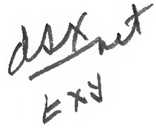
COLLEGE BOTANY

STRUCTURE, PHYSIOLOGY AND ECONOMICS OF PLANTS

MELVILLE THURSTON COOK, PH.D.



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STRUCTURE, PHYSIOLOGY AND
ECONOMICS OF PLANTS

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Utilization of plants in ornamental plantings.

COLLEGE BOTANY

STRUCTURE, PHYSIOLOGY AND ECONOMICS OF PLANTS

BY

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PREFACE

THIS work is the outgrowth of the author's class work and is an effort to meet present conditions. It is an effort to present as many different phases of the subject as possible and to give the student a very general and very broad view. It is an effort to meet the criticisms that botany, as taught in recent years, is unsatisfactory and unsuited to the needs of the student, and to meet the demands for applied botany by making a combination of the elementary principles of pure and applied science. Or, rather, to present the fundamental principles of botany and at the same time give some idea of the lines of application of the subject, which are to be taken up in more advanced courses.

The book is intended as a guide for the student, but it is expected that the teacher will expand, reduce or modify such parts as may be necessary to meet conditions or as may be necessary to meet his or her ideas of the best method of presenting the subject. Neither the teacher nor the student should be a slave to a text-book of any kind. Books are the records of the work of others and methods for the guidance of the students, but there is no botany in the book; the study of botany is the study of plants.

The book is not complete; it is intended as an introduction, which must be expanded in more advanced courses which may be adjusted and planned to meet the student's needs. However, it is hoped that it will give a broad viewpoint to those who wish to take up the advanced study of the subject, and that those who do not expect to continue the subject will learn to appreciate its importance.

The writer wishes to express his thanks to Prof. William T. Horne, Professor Guy West Wilson, Professor G. W. Martin, Dr. J. J. Taubenhaus, Dr. W. H. Martin and many others for valuable suggestions and for assistance in reading the manuscript and proof. Also to Miss Gertrude E. Macpherson, Mr. R. F. Poole and to Mr. E. West for the many illustrations prepared by them.

THE AUTHOR.

August, 1920.

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INTRODUCTORY

Botany.—Botany is the study of plants and plant life. It involves not only the study of the individual plant but also the study of plants in relation to each other and in relation to soil, temperature, water supply, light, other living organisms and many other factors. It may be expanded to include the problems of plant production and the utilization of plant products.

Botany is very much misunderstood by many people who look upon it as a somewhat ornamental subject without any particular relation to any other branch of learning, either cultural or applied. However, it is both a cultural and an applied science of the greatest value. It is a cultural subject in that it trains the student in a new line of thought, gives a new method of reasoning and helps in the development of the scholar. It develops the powers of close observation and accuracy in methods of work. It also opens a new field for the enjoyment of the beauties of nature and for the appreciation of literature. It is an applied science in that it is so closely associated with the problems of life. It not only involves the production and utilization of plants, but it involves the laws of evolution which govern all forms of life.

In fact, the very existence of animal life depends upon the presence of plant life. Progressive agriculture is very closely associated with botany: (1) through the study of chemistry of the soil and fertilizers most satisfactory for plant growth, (2) through the study of plant breeding for the development of new and valuable varieties of crop plants of various kinds, (3) through the studies of chemistry and physics for the determining of the relationship of the plant to water, temperature, light, air and other environmental factors (*i.e.,* plant physiology), (4) through the study of geology for the relationship of the distribution of plants to the earth surface (*i.e.,* plant geography).

The word "botany" is derived from the Greek word "bosko," meaning "I eat," and is significant of the importance of plants to mankind. All animal life is dependent either directly or indirectly on plants for its food and man is dependent on the plant not only for food but also for clothing, fuel, much of his building material and about 90 per cent. of his drugs.

Since plant life is necessary for the existence of all animal life, including mankind, it is very evident that agriculture is the primary and most important industry of the human race and that its highest development is dependent on a knowledge of plants and plant growth. The increase in population with its demands on agriculture for food, clothing and other necessities of life will make a thorough knowledge of botany of more and more importance.

Botany is divided scientifically into the following branches:

(*a*) *Morphology,* which treats of the form and structure (anatomy) of plants and includes *histology,* treating of the microscopic structure, and *embryology,* treating of the origin and development of the young plant. It involves a study of the structure of the different parts in their development from seed to fruiting. It takes into consideration both the very simple forms of plant life and the very complex and highly developed forms and aids in establishing their relationship and evolutionary history.

(*b*) *Physiology,* which treats of the functions of the plant and includes *ecology,* treating of the activities of the plant in the field, and *plant geography,* treating of the distribution of plants over the face of the earth. It involves a study of the materials which the plants use in growth and their methods of securing and utilization of them. It also includes a knowledge of the relationship of the plant to its environmental factors; such as soil, water, light, air, temperature and to other organisms. It will be readily seen that any extensive study of plant physiology necessitates a knowledge of chemistry and physics.

(*c*) *Taxonomy* or classification which treats of the grouping of plants with reference to their relationship to each other; *i.e.,* their similarities and differences. This is one of the oldest divisions of botany and is fundamental for a thorough knowledge of any other branch of the subject. The masters of this division of botany have placed all plants into four large groups (page 7), which have been sub-divided into orders, the orders into families, the families into genera and the genera into species. A knowledge of this phase of the subject enables the student to determine the name of a plant and its relationship to other plants with comparative ease.

As an applied science, botany may be divided arbitrarily into the following subjects: (*a*) *Agricultural botany,* dealing with the growing of all kinds of agricultural plants. (*b*) *Agronomy,* dealing with the production of field crops. (*c*) *Horticulture,* dealing with the production of fruit and vegetable crops. (*d*) *Floriculture,* dealing with the production of ornamental plants. (*e*) *Forestry,* dealing with the production, conservation and utilization of forest and shade trees. (*f*) *Seed testing,* dealing with the testing of seeds to determine their purity and power of germination. (*g*) *Pharmacology,* dealing with the production and utilization of drug plants. (*h*) *Plant pathology,* dealing with the cause, control and eradication of plant diseases. (*i*) *Bacteriology,* dealing with the study of bacteria (page 250).

These branches have been separated from botany and organized as independent branches of learning. However, botany is fundamentally the basis for all of them and their highest development will depend largely on their close relationship to the parent subject. Plant pathology is the youngest of these applied subjects and is necessarily most closely attached to the parent subject. The diseases of the higher plants are mostly due to the lower forms of plant life. Therefore, the plant pathologist must have an understanding of both the higher and the lower forms of plant life.

Botany is not primarily the learning of technical terms, definitions and the scientific names of plants. It is the study of plant life in all its various relations. It cannot be studied in the same manner that we study many other subjects; it cannot be studied from text-books. The books contain records and methods, but the *study of botany is a study of the plant.* The statements in the books are based on our present knowledge of the subject; but we are learning new facts; our knowledge is advancing and our books are constantly undergoing changes in accordance with these new facts. It is said that one of Agassiz's mottoes was: "Study nature, not books." This should be the motto of all students of botany.

The proper study of botany not only gives us a knowledge of plants in their various relations, but it also develops our power of close observation and accuracy; our ability to see things that we have not seen, to see things as they are, to properly interpret what we see and to make accurate records of our observations and interpretations. A knowledge of chemistry, physics and geology is necessary for a thorough understanding of botany and a knowledge of botany is necessary for the highest development of agriculture, agronomy, horticulture, floriculture, forestry, plant pathology and other applied branches of the subject.

Plants are more or less generally distributed over the greater part of the earth's surface, and in many cases are the most predominant features in the landscape. Some live in very dry regions, while others are found in the swamps, and still others are attached, or floating in both fresh and salt waters. In fact, the animal life of the waters is dependent on the aquatic plants in the same manner that land animals are dependent on land plants. Some plants live in the very cold parts of the earth, while others live in the extremely warm regions; in fact, some of the low forms of plants live in hot springs at a temperature approaching the boiling point. Some plants live on other plants and some live on animals. A very few parts of the earth, such as the extremely cold regions, volcanic areas, desert regions and certain salt deposits are without plant life. A knowledge of the features of the earth's surface combined with a knowledge of the conditions necessary for the growth of different species of valuable, economic plants, has enabled man to introduce plants from one part of the world to other parts with great profit to the human race. Some of the arid and semi-arid regions have been irrigated and the conditions so changed as to make high plant production possible.

Plants vary greatly in form and general appearance. Some of them are so extremely small that they cannot be seen without the aid of a very high-power microscope, while others are of very great size. Their processes of life vary greatly with the conditions under which they live. We very generally consider the higher plants of the greatest importance to man, but a knowledge of botany leads us to an appreciation of the very great importance of the apparently insignificant forms of plant life. Some of these extremely small plants are of great importance in certain industries, while others are the causes of diseases of higher plants and of animals. We will give the greater part of our attention to the higher forms of plant life, to the flowering plants.

These higher plants consist of three parts, the roots, stems and leaves; the other parts, such as flowers and fruits, are specializations of some one or more of these primary parts. The roots serve for anchorage or holdfasts, for the securing of water and certain food materials and for storage; the stems connect the roots and the leaves and serve some other functions; the leaves absorb the energy of sunlight and serve for transpiration, photosynthesis and other functions. The flowers and fruits are leaves which are specialized for reproduction. The functions of these organs will be explained more fully in later chapters.

These higher plants grow from seeds, eventually producing another generation of flowers and seeds. Some plants complete this cycle in one season and are known as *annuals;* others complete their cycle in two years and are known as *biennials;* while others live for many years, producing seeds year after year, and are known as *perennials.* Some flowering plants have partly or completely lost the power of producing seeds and reproduce vegetatively (pages 101–107).

The plant is made up of many kinds of cells which are microscopic in size and variable in form and function, dependent on their location in the plant and the functions which they perform.

These cells are grouped into a tissue which must be studied with the microscope and these tissues make up the organs, such as stems, roots and leaves. Having gained a thorough knowledge of the character and arrangement of these tissues, it becomes possible to make an intelligent study of their functions and the conditions which influence and control plant growth. This may be followed by a study of the classification of plants and the utilization of plant products.

The groups in the plant kingdom from lowest to highest may be represented as follows:

Thallophytes	Algæ	Chlorophyll-bearing (*i.e.* green) plants of simple structure and with simple methods of reproduction. They range from minute forms which cannot be seen without a microscope to very large forms. They are mostly aquatic. (See page 260.)
	Fungi	Non-chlorophyll-bearing plants of simple structure and methods of reproduction very similar to the algæ. (See page 273.)
Bryophytes	Liverworts	Plants which are more complex than the Thallophytes but far more simple than the higher plants. The reproductive structures are much more complex than in the Thallophytes. (See page 289.)
	Mosses	Plants which are similar to the liverworts but of a more complex structure. (See page 292.)
Pteridophytes	Ferns and related plants	The members of this group have a structure which in many respects is comparable to the higher plants, but the methods of reproduction are very similar to the Bryophytes. (See page 297.)
Spermatophytes (higher plants).	Gymnosperms	Seed-bearing plants usually known as conifers or cone-bearing plants. They are mostly evergreens. (See page 303.)
	Angiosperms	Flower- and seed-bearing plants. Mostly deciduous. (See page 312.)

For convenience in study we will divide the subject into three parts as follows:

Plant structures, in which we will study the structure of the higher plant (see page 9);

Plant activities, in which we will study the physiology of the plant (see page 147); and

Classification and economics, in which we will study the classification and uses of plants (see page 255).

PART I

PLANT STRUCTURES

For the convenience of study, we may consider the plant as a machine consisting of many delicate parts. In order to understand the working of this machine, it is first necessary to understand the construction of the machine. Therefore, Part I of this book is devoted to the study of the structure or anatomy of the plant.

CHAPTER I

THE CELL

THE **cell** is the unit of the living organism whether plant or animal. That is, all organisms, both plants and animals, are made up of one or more cells. The term *cell* is generally used to imply a minute box-like structure with walls which may or may not be filled with protoplasm or other substances; but a living, organized body of protoplasm may be considered a cell, regardless of the presence or absence of the cell wall. Of course, the empty cells which we see under the microscope were at one time filled with protoplasm. Plant cells vary in diameter from 1/1000 to 1/100 of an inch and can be readily seen in a thin piece of plant material when examined under a microscope.

Historical.—Of course, our knowledge of the cell began with the invention of the microscope, for it was impossible to see the cell previous to that time. Robert Hook (1635–1703), an Englishman, was one of the early workers with the microscope and was the first to demonstrate the cell about the year 1660. He studied thin sections of plants and used the term "cell" in describing the structures which he saw, comparing them with the cells of the honeycomb. Marcello Malpighi (1674) (Fig. 1), an Italian, and Nehemiah Grew (1682) (Fig. 2), an Englishman, added greatly to our knowledge of plant cells and are frequently called the "fathers of plant anatomy." The microscopes used by these early workers were extremely crude as compared with the highly complex instruments of to-day, and they were unable to recognize anything other than the cell walls.

Protoplasm.—After years of study, accompanied by improvements in the microscope, some of these early workers recognized that growing cells were filled with a living substance which was evidently the most important part. The demonstration that this substance was the essential factor in the cell was accomplished by Schleiden (Fig. 3) about 1838. In the following year the same thing was demonstrated for animals by Schwann. In 1855 Unger called attention to the great similarity of this substance in the plant and animal cells. This substance was described under many names, but is now very generally known as protoplasm, a name first used by von Mohl (Fig. 4) about 1840. It is now very generally recognized that protoplasm is the living part of the organism, whether it be plant or animal, and that the protoplasm of the plant and animal are indistinguishable by any known methods. The term "protoplasm" is from the two Greek words *protos,* meaning "first," and *plasma,* meaning "formed" or "created," and refers to the beginning of life.

The meaning of the word "cell" has changed with our advance in knowledge, but its use is so general that it is very difficult to substitute another term with a more definite meaning. Some workers prefer to use the word "protoplast" for the cell wall and contents, while others use the word cell in referring to the cell wall and "protoplast" in referring to the living protoplasmic contents.

Protoplasm is a semi-fluid, albuminous substance in which life makes itself manifest. It is more nearly like the white of an egg than any other substance with which we can compare it. It is difficult to give a scientific definition of life, but the distinctive characters of a living organism are: (*a*) complex chemical composition; (*b*) metabolic action, *i.e.*, the power of change

Fig. 1.—Marcello Malpighi, Father of Plant Anatomy.

Fig. 2.—Nehemiah Grew, Father of Plant Anatomy.

Fig. 3.—Matthias Jakob Schleiden demonstrated the importance of protoplasm.

Fig. 4.—Hugo von Mohl, who first used the term "protoplasm."

Fig. 5.—Robert Brown, who discovered the nucleus.

involving growth, waste and repair (see Chapter XVIII), and (*c*) the power of reproduction (see Chapter VII). The chemical composition of living protoplasm cannot be accurately determined, since the methods employed by the chemist must necessarily result in the death of the protoplasm. Therefore, the analysis must be made of the dead protoplasm, which probably differs in some degree from the living protoplasm. However, it is evident that protoplasm contains carbon, hydrogen, oxygen, nitrogen, sulfur and in some cases other elements. We are unable to distinguish differences between plant and animal protoplasm, or between the protoplasm of low and high forms of life.

The *protoplasm* is composed of two parts, the *cytoplasm* and the *nucleus*. The cytoplasm appears granular or web-like, dependent upon the power of the microscope in use, and may be compared to an extremely delicate sponge. The spaces between the delicate web or net-like structures are known as *vacuoles* and are usually filled with *cell-sap*, which consists of water containing sugar, salts and other soluble materials. Every free surface of this cytoplasm (such as the outer surface and the surfaces of the vacuoles) is organized into what is known as the *plasma membrane*, which is evidently very important but is not well understood. It is about .0003 inch thick and lies so close to the cell wall that it is very difficult to detect. However, it can be demonstrated by treating the living cell with 5 per cent. salt solution, which causes the protoplasm to shrink.

The *nucleus* of the cell was discovered by Robert Brown (Fig. 5), an Englishman, in 1831. It is usually spherical, is composed of dense protoplasm, which is sometimes called "nucleoplasm," and is surrounded by a delicate membrane known as the *nuclear membrane*. It usually contains one, sometimes more, very small bodies known as the *nucleoli* (singular, *nuceolus*). The most important substance in the nucleus is the *chromatin*, which will be described later (see page 129). The nucleus is believed by many to exert a controlling influence over the activities of the cell. If the cell is divided into two parts, one with and one without the nucleus, the former can produce a new wall, while the latter is unable to do so and soon dies. The nucleus is also believed to cause the oxidation within the cell and to be the most important factor in heredity (see Chapter X).

Cell Wall.—The outside covering of the protoplasm is known as the cell wall. It is the product of the protoplasm, but is not living material. It may be considered the skeleton of the cell. It is frequently perforated with very minute pores for the passage of very delicate threads of cytoplasm which connect the protoplasmic contents of neighboring cells. When young, and sometimes throughout the entire life of the cell, the wall is composed of cellulose $(C_6H_{10}O_5)_n$, which expands with the growth of the cell. In most cases, it becomes modified into *lignin* (in bast and wood cells), *cutin* (in epidermal cells), and *suberin* (in cork cells). These modifications are due to the impregnation of the wall with other compounds and may serve many purposes; they may give strength, as in the bast and wood cells, or may serve for protection against water and other factors, as in the case of the cutin covering of leaves and the suberin of the bark cells. Sometimes parts of the cell wall become gelatinous and capable of absorbing great quantities of water. This is very characteristic of the seed coats of certain seeds. In some cases, such as the date, the cellulose serves for plant food in the germination of the seeds. A knowledge of the structure and chemical character of plant materials is of very great value in many of our important industries. The growth is both internal (intussusception) and external (apposition). The animal cell wall differs from the plant cell wall in that it usually contains nitrogen.

Cell Contents.—In addition to the living protoplasm, the

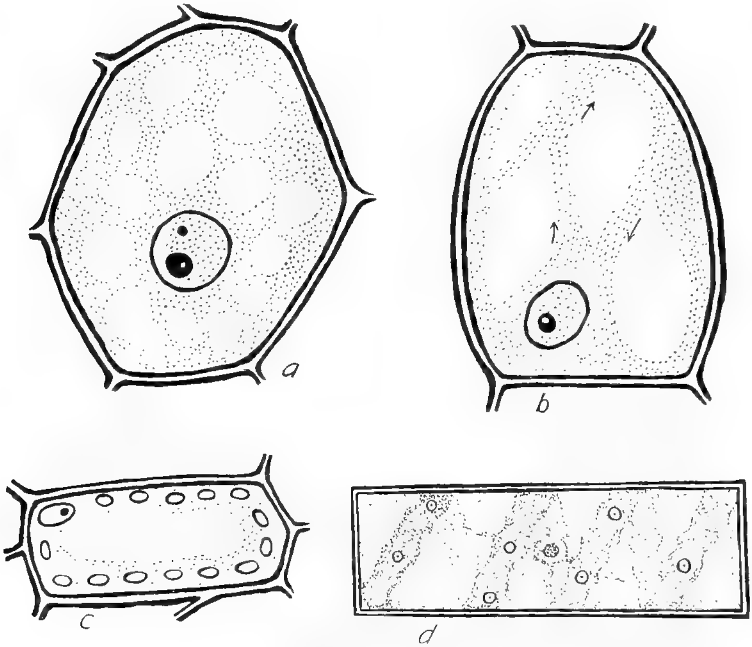

FIG. 6.—Typical plant cells. (*a*) Diagrammatic drawing showing parts of a cell; (*b*) cell from stamen hair of *Tradescantia* showing movement of protoplasm; (*c*) palisade cell from leaf showing nucleus and chloroplasts; (*d*) cell of *Spirogyra* showing nucleus and chloroplasts.

cell may contain many other bodies and compounds, some of which are protoplasmic in character, while others are non-protoplasmic.

The most important protoplasmic bodies of the cell (Fig. 6) are: (1) The *cytoplasm,* to which we have already referred. (2)

The *nucleus* and *nucleolus,* to which we have also referred. (3) The *plastids,* which are variable in size and form and are divided into three groups dependent on color but are in reality the same thing. They are as follows: (*a*) The *leucoplasts,* which are colorless. (*b*) The *chloroplasts,* which are developed from the *leucoplasts* and carry the green coloring matter or *chlorophyll.* (*c*) The *chromoplasts,* which carry other coloring materials and are developed from the *chloroplasts.* In the parts of the plant which are not exposed to the sunlight we find leucoplasts only. But when these parts are exposed to the sunlight the leucoplasts are transformed into chloroplasts and the parts become green. This is well illustrated when potatoes are exposed to the sun. The color in flowers and ripe fruits is due to the fact that chloroplasts have become chromoplasts and contain the coloring materials. (*d*) The *mitochondria* or *chondriosomes* found in cells are very small elongated bodies in the cytoplasm; we know very little concerning their character or importance.

The most important *non-protoplasmic* bodies and compounds found in the cell are (1) *chlorophyll,* which is the green coloring material. It is confined to the chloroplasts and absorbs energy from the sun, which it utilizes in the formation of sugar and starch (see page 195). (2) The other *coloring materials,* which are very generally found in the flowers, fruits and other parts of most plants. (3) *Cell sap, sugars, starch, gum, fats* and *oils, proteins, aleurone, resins, acids, alkaloids, tannins, crystals* of various kinds and many other compounds. These compounds exist in various amounts in different parts of the plant and are the factors which determine the value of the plant for food and other uses. This question will be discussed more fully in Chapter XI on plant products.

From a study of the preceding it will be readily seen that the contents of an active living cell are undergoing constant changes and that the cells in various parts of the plant body are different. These changes are extremely complicated and involve the taking in of food materials from the soil and air which are transformed into true food materials, the digestion of foods, the making of new cells, the growth and the modification of cells in various parts of the plant.

Properties of Protoplasm.—Protoplasm has certain very definite and characteristic properties. The most remarkable of these properties is *life,* which is a characteristic that man has never been able to explain. The other properties will be considered very briefly at this time and be discussed more fully later; they are: (1) *movement,* which may be seen in the cells of the leaves of *Elodea* and in the cells from the stamen hairs of *Tradescantia* and other plants. It is a streaming, circular movement; (2) *irritability,* in response to stimulation by heat, cold, touch, electricity and other stimulants; (3) *assimilation* and *growth,* that is, the taking into itself of compounds which it uses for growth and repair; (4) *reproduction,* or the ability to make new cells (see page 129).

Cell Growth and Division.—The growth of plants is the sum total of the growth and division of the individual cells of which it is composed. In fact, all the activities of the plant are the sum total of the activities of the living cells of which it is composed. Therefore, the cell is both the anatomical and living physiological unit of the plant. The structure of the living cell and its physiological activities are extremely complex. A recent writer has very aptly expressed this idea as follows: " The vital processes exhibited by a cell indicate a complexity of organization and minuteness in the details of its mechanism which transcend our comprehension and baffle the human imagination, to the same extent as do the immensities of the stellar universe." The processes of cell growth and division will be much better understood later in our course and will be taken up again in Chapter X.

What is a Plant?—In speaking of plants we usually refer to the higher plants which are very complex in anatomical structure and in physiological activity. But, if we think of the plant kingdom as a whole, we find a wonderful range from the very simple microscopic, unicellular plant to the very complex plants referred to above. The simplicity applies to the structure rather than to the functions, for we find the unicellular plants perform very complex physiologic functions. If we make a study of a series of plants from the lowest to the highest (see Chapters XXIII and XXX) we find a gradual modification from plants composed of one or a few cells of the same character to plants composed of great numbers of cells which are very different in structure and which are grouped in a very definite manner, and finally by the formation of very definite plant organs, such as leaves, stems and roots. This gradual modification and grouping of cells is accompanied by a corresponding change in physiological functions. In the lower plants each cell may perform any or all of the functions of the plant, but in advancing from the lower to the higher groups we find a distribution of functions among the modified cells and finally very evident divisions of labor among the cells and organs of the plants.

We will begin our work by studying the higher plants, those with which we are most familiar. These higher plants are very complex in both structure and function. In general, they consist of three primary parts: stems, roots and leaves. The various other parts, such as buds, bulbs, flowers and fruits, are modifications of these primary parts. We will give our first consideration to the anatomy, histology and reproduction of these plants. Second, to the physiology of plants. Third, to the taxonomy and utilization of plants.

LABORATORY EXERCISES.

Purposes.—Laboratory work is not only for the purpose of learning facts concerning plants and plant growth, but also for the purpose of developing the powers of close observation and accuracy. The drawings and notes are records of the work and good index of the ability of the student. Neatness is essential to good work, but artistic finish although very desirable is of minor importance. Study the subject carefully and thoroughly before attempting to make the drawings.

Microscope.—The microscope is a complicated piece of apparatus and should be properly cared for. It consists of two optical parts which are supported by a mechanical stand. The two optical parts are set in either end of a tube, the upper end known as the ocular and the lower as the objective. The light is concentrated and reflected by a mirror so as to pass through the object to be studied, thence through the two optical parts. The objective forms an image of the object which is magnified by the ocular. The student should learn the general principles involved in the use of the microscope before beginning the study of objects.

Exercise 1. Examine prepared slides of pollen grains or other material showing *individual cells* of various forms and sizes.

Exercise 2. Examine the green slime found growing in damp places, on the bark of trees, brick walls, etc. Note the cell walls, cell contents and cell divisions.

Exercise 3. Examine the cells of *Spirogyra*. Note the size and shape of the cells and their relation to each other. Note the cell walls, the protoplasm and the chromatophore (or chloroplasts). Why does a part of the chloroplast appear bright and the other part dim? Do you see the nucleus?

Examine some of the *Spirogyra* that has been kept in alcohol for 24 hours or longer. What is the effect? Do you see the nucleus? Add a drop of eosin to the preparation. What is the effect?

Examine some of the *Spirogyra* that has been kept in 5 per cent. salt solution for a few minutes. What is the effect?

Exercise 4. Tear off a portion of the skin from the fleshy part of an onion. Soak in eosin and examine under the microscope. Note the cell walls, protoplasm, nuclei and vacuoles.

Exercise 5. Examine the cells of a very young leaf of *Elodea canadensis* (which is a common water weed) under the compound microscope. Note the shape of the cells, cell walls, cell-contents and general appearance of the cells. Give special attention to the protoplasm, nucleus and chloroplasts. Does the protoplasm move?

Exercise 6. Examine the hairs from the very young, actively growing stem of a *Petunia* or from the stamens of any wild or cultivated species of *Tradescantia*. Note the number, form, size and shape of the cells; the cell wall, nucleus, chloroplasts and protoplasm. Does the protoplasm move?

Exercise 7. Examine sections of several green plants. Note the chloroplasts. Are they of the same size and shape?

Exercise 8. Examine thin sections of a new tuber of a potato. Note the cells. Look for leucoplasts. Stain with iodine and note the starch grains.

Exercise 9. Examine cross sections of the petals of colored flowers, of the colored leaves of the *Coleus* and of the root of the beet. Where are the colors located?

Exercise 10. Add a drop of a mixture of iodine and phosphoric acid to a thin section of plant with prominent cell walls. It stains the cellulose a violet blue. It is prepared by dissolving with heat ½ gram of potassium iodine and a few iodine crystals in 25 c.c. of concentrated aqueous solution of phosphoric acid.

Note—Other products of the cell will be studied in Chapter XI.

CHAPTER II

ELEMENTARY TISSUES

Variation in Cells.—Cells vary greatly in size, shape, thickness of cell wall, markings of cell wall and in contents. These modifications can all be traced from the simplest and most primitive of cells. The cells of the lower plants are very simple and very similar in structure, chemical composition and functions, but in succeeding higher groups we find gradual changes in character involving all these points. In the young embryo of the higher plants we find the cells are the same in structure, chemical composition and function; but with the development of the embryo and seedling we find the formation of new types of cells which perform special functions. The complexity of the plant varies primarily with its position in the plant kingdom. These variations and groupings of cells give rise to what are known as tissues.

A **tissue**, therefore, may be defined as a group of cells similar in origin, structure and functions. All plants, regardless of complexity, begin as single cells, and the great variety of cells, tissues, systems and organs hereafter described are derived from these individual cells as a result of growth, cell division and cell modification. This gradual modification of a cell or group of cells for the performance of a particular function is known as *differentiation* and results in the formation of a number of elementary tissues, which will be described in this chapter.

Parenchyma (Fig. 7).—This tissue is composed usually of thin-walled cells, which are generally large and loosely attached, thus permitting numerous intercellular spaces. It is the most primitive and most abundant tissue in the plant kingdom. The lower forms of plant life are composed entirely of parenchyma tissue. The young embryo of the higher plants is composed entirely of parenchyma cells, which undergo differentiation resulting in the formation of the tissues found in the various parts of the mature plant and described in this chapter. The growing parts of a plant are always composed of parenchyma cells and are known as the *meristematic tissue* or *meristem* (see page 27). The parenchyma tissue is found in many parts of the plant, especially in the cortical region, the pith, the leaf, the fleshy roots, the fruits and seeds and many other parts of the plant. The edible parts of the plant are composed largely of parenchyma tissue, their value as food depending on the thin walls of the cells, the food stored in the cells and the absence of injurious or objectionable substances.

Collenchyma (Fig. 7).—The cells of this tissue are usually called the "thick-angled cells." They are derived from the parenchyma cells but differ from them by having somewhat thicker walls, especially at the angles, somewhat smaller cavities, and fewer and smaller intercellular spaces. They are frequently filled with protoplasm and starch. They are much more regular in size and arrangement than the parenchyma cells and are most abundant in the stem and petioles of herbaceous plants, especially those with angular stems. They are found just beneath the epidermal structures and are of some commercial importance in certain medicinal plants.

The collenchyma is a strengthening tissue and is very abundant in some of the herbaceous plants. In many cases the parenchyma does not appear to serve any very important function; but in others it serves for the storage of reserve foods. The parts of the plants that we use for food are made up almost entirely of parenchyma cells.

Sclerenchyma (Fig. 7).—This tissue is derived from the parenchyma and is composed of cells with thickened walls, which are frequently referred to as hard or stony cells. They are usually irregular or polygonal in shape, but may be elongated or even branched. The walls are thick, lamellated and porous. The pores may be simple or branched. The cell cavity is usually small and during the early life of the cell is lined by a thin layer of protoplasm. These cells frequently contain tannin, calcium oxalate crystals, starch and other substances. The shells of nuts are made up almost entirely of these cells. This tissue is also found in varying amounts in roots, stems, leaves and fruits of various plants. It serves primarily for the protection of delicate and nutritious parts against animals that would use them for food and against the elements of nature that would destroy them. The fibrous cells are sometimes sclerenchymatized.

Prosenchyma or Fibrous Tissue.—This tissue is derived from the parenchyma (Fig. 7). The cells are usually very much elongated, sometimes being more than an inch in length and interlaced or dove-tailed so as to form very strong structures. They are found in all parts of the plant, but are especially abundant in the stems and roots. They show so many modifications that it is necessary to subdivide them into smaller groups: bast fibers and wood fibers.

(1) The *bast fibers* are long cells with thick walls. The cell walls may remain cellulose or become very much lignified. They are most abundant in the inner layers of the bark and give both strength and flexibility to the stem. In the herbaceous plants

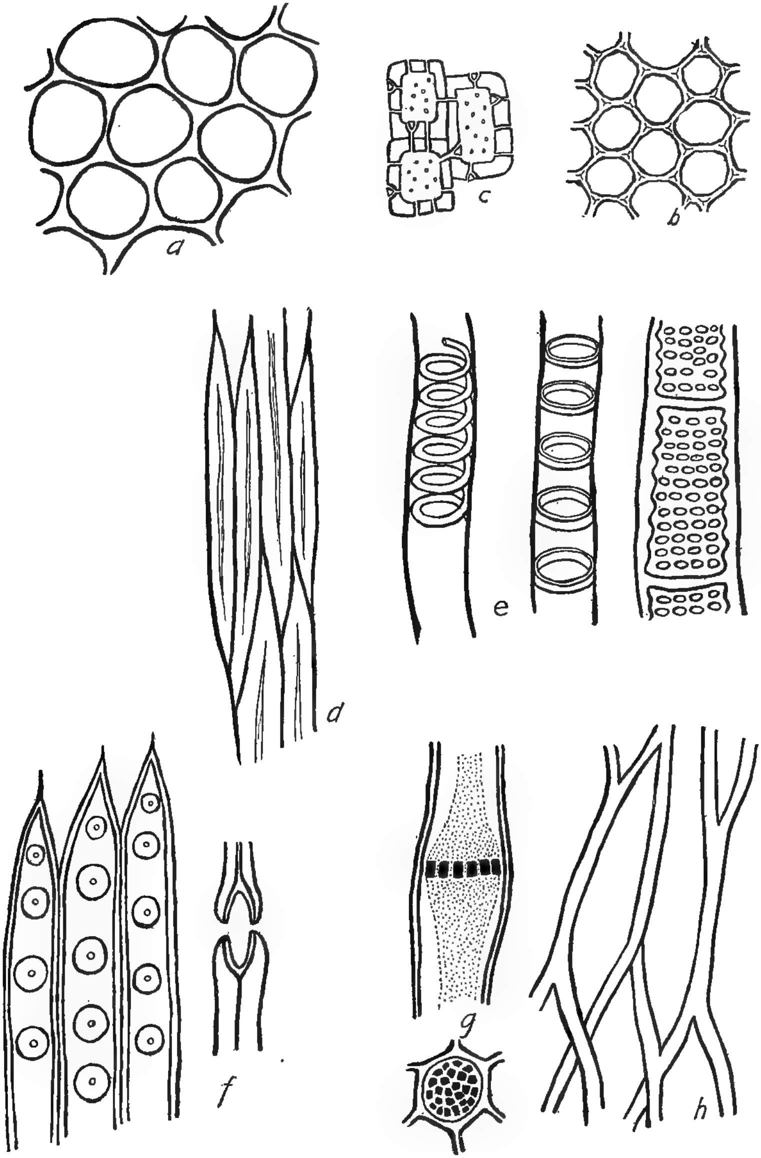

FIG. 7.—Tissues. (*a*) Parenchyma; (*b*) collenchyma; (*c*) sclerenchyma; (*d*) fibrous; (*e*) tracheary; (*f*) tracheids; (*g*) sieve; (*h*) laticiferous.

they may be more abundant than the wood fibers. They are the important commercial products in many of our fiber-producing plants, such as hemp and flax, and are used in the manufacture of cloth, cordage and many other textiles.

(2) The *wood fibers* are very similar to the bast fibers but are usually somewhat shorter. The cell walls are thick and lignified. They constitute the woody parts of the plants and in the dicotyledonous plants are located farther below the surface of the stem than the bast fibers. The quality or character of a wood depends on the specific gravity, hardness, elasticity, strength and other characters of these fibers. They also give strength to the plant. Closely associated with the wood fibers are the tracheary tubes and the tracheids. In fact, they are modified wood fiber cells. The sieve and laticiferous cells are also modified fibrous cells.

The *tracheary tubes* (Fig. 7) are formed from fibrous cells by the partial or complete dissolving of the cell walls at the ends of certain long fibrous cells accompanied by a modification of the lateral cell walls, resulting in the formation of long tubes. The modified cell walls are due to peculiar lignin thickenings on the inner surfaces of the walls resulting in the formation of various patterns described as *ring, spiral, reticulated, dotted,* or *pitted tracheary.*

In the *ring tracheary tubes* the thickenings take the form of rings attached to the inner walls and projecting into the cell cavity; in the *spiral tracheary* the thickenings are very much like a spiral wire spring just fitting into the tube; in the *reticulated tracheary* the thickenings form a network on the inner surface of the cell wall; in the *dotted* or *pitted tracheary* the thickenings are such as to leave numerous thin spots or pits.

The *tracheids* (Fig. 7) are more or less spindle-shaped short cells with pitted walls and are closely fitted together. They are very abundant in many plants and are the characteristic woody tissues of the coniferous trees, such as the pines.

The cell walls of wood fibers also contain, in addition to cellulose, a substance known as *lignin*. Its chemical composition is not definitely known, but it has elements and properties very similar to cellulose. The fibrous tissues serve not only for the strengthening of the plant but also for the conduction of certain liquid and food compounds from place to place in the plant.

Sieve Cells (Fig. 7).—The sieve cells are modified fibrous cells and are a part of the fibrous tissue. They are elongated cells and in vertical rows. The vertical walls are thin, but the transverse walls are thick and perforated with numerous openings, permitting a free intermingling of cell contents. These transverse perforated walls are known as sieve plates. The sieve cells serve for the conduction of foods.

Laticiferous Cells (Fig. 7).—The laticiferous cells belong to the fibrous tissue and are in simple or branching rows and are sometimes modified into tubes. They are found in plants that produce latex, that is, milky or sometimes colorless juices, and are usually more or less closely associated with the sieve tubes. They are especially common in milkweeds, rubber plants and also occur in many other plants. They contain oils, resin, mucilage, alkaloids and many other products well known to commerce. They serve for the conduction of these products.

System.—A system is composed of one or more tissues and serves for the performance of certain plant functions. They are as follows: The *fundamental system* or *primary meristem,* the *epidermal,* the *fibro-vascular* and the *ground systems.*

(1) The *fundamental system* or *primary meristem* is composed of undifferentiated (*i.e.*, parenchyma), *actively growing* and *dividing cells*. Cells of this kind are very simple in structure, very rich in protoplasm and very active during the growing season. They give rise to all of the various types of cells and tissues which we have just studied. In some of the lower plants all the cells have this power of growth and division, but in the higher plants the cells which possess this power are restricted to certain locations which will be discussed in Chapter III. They can be classified in two groups, the primordial meristem and the cambium (see page 46). The sexual and the embryonic cells also belong to this system (see Chapter VII).

(2) The *epidermal system* is composed of cells which form the surface covering of the plant. This system is composed of modified parenchyma cells which are usually cutinized. It includes the outside layer of cells of leaves and other very delicate parts of the plant, the delicate appendages (trichomes) which are found on various parts of the plant and which serve for protection in some cases and for absorption in others. Stomata and secretory cells are also found in the epidermal system (see pages 78 and 81). In some plants the epidermis is apparently made up of more than one layer of cells, but in most cases of this kind the lower layers are derived from the ground meristem and are not true epidermal cells. The epidermis on the stems of perennial shrubs and trees is replaced by a cork covering which is frequently referred to as the epidermal system.

(3) The *fibro-vascular system* is composed of fibrous tissue of various kinds. It is both the strengthening and the circulatory system of the plant and is of the very greatest importance in the very large and highly developed plants.

(4) The *ground system* includes the pith, which is parenchyma, the collenchyma and such other tissues as are not included in the other systems.

Organ.—This term is applied to a definite part of a plant, such as root, stem, leaf, tendril, flower, part of a flower or fruit, which is composed of tissues and has a definite structure and definite function. Some organs are very simple in structure and function, while others are very complex. Strictly speaking, there are but three primary organs in the higher plants: the stem, root and leaf. The other parts, which are usually referred to as organs, such as the flowers, fruits, tendrils and thorns, are in reality modifications of some of the primary organs.

Review.—The *cell* is the structural and physiological unit of the plant. It is composed of protoplasm and possesses a nucleus. The protoplasm is usually surrounded by a cell wall. The cell may contain plastids, mitochondria, chlorophyll and other pigments, sugar, starch, gums, proteins, fats, oils, resins, acids, alkaloids, tannins, crystals and other compounds. The simplest types of cells are thin walled, but may be of almost any form; they give rise to many varieties of cells. A *tissue* is a group of cells which are alike in origin, structure and function. A *system* is one or more tissues which serve a special function. An *organ* is a definite part of a plant body, serving one or more functions. The systems and organs will receive further consideration in the succeeding chapters.

LABORATORY EXERCISES.

The greatest variety and complexity of tissues are to be found in the higher forms of plants. The *parenchyma* is the simplest type of tissue and gives rise either directly or indirectly to all other tissues.

Exercise 1. Parenchyma tissue. Examine thin sections of the pith of elder or other plant with large pith, such as stems of corn or young herbaceous shoot. Note the large, thin-walled, isodiametric, overlapping cells and the intercellular spaces. Test for cellulose (page 145).

Exercise 2. Examine thin sections of potato tuber, apple and fleshy roots and note the same points as in Exercise 1.

Exercise 3. Examine a thin cross section of a leaf. It is composed almost entirely of parenchyma tissue.

Exercise 4. Collenchyma tissue. Examine thin sections of *Begonia* stems and locate the cells with thick walls, especially at the angles.

Exercise 5. Sclerenchyma tissue. Examine sections made from *Dahlia* root and note the thick-walled cells. Also note the canals running through the walls.

Exercise 6. Examine sections of the shells of any nuts that may be convenient and note size and character of the cells.

Exercise 7. Fibrous tissue. Examine thin longitudinal section of the wood of Basswood (*Tilia americana*) which have been macerated by heating in a test tube in nitric acid with a little potassium chlorate. Tease the cells apart with needles. Note shape and arrangement of the cells.

Exercise 8. Do the same with the inner bark and note the bast cells. Compare with wood fibers.

Exercise 9. Tracheary cells. Examine longitudinal sections of the corn stem and note the different kinds of tracheary cells.

Exercise 10. Tracheids. Examine radial sections of pine wood and note the tracheid cells.

Exercise 11. Sieve tissue. Examine longitudinal sections of pumpkin vine that have been preserved in 99 per cent. alcohol. Note the sieve tissue.

Exercise 12. Laticiferous tissue. Examine longitudinal sections made from the inner bark of the milkweed or spurge. Note the laticiferous tissue.

CHAPTER III

STEMS, BULBS AND BUDS

THE **stem** may be defined as that part or organ of the plant which serves to connect the root and leaves, two sets of organs with very different relationships and functions. In the woody plants, the fibro-vascular system predominates in the stems, but in the herbaceous plants the parenchyma and collenchyma tissues are more abundant. The stem of the woody plant also has a more or less highly developed covering of bark, while the stem of the herbaceous plant has a comparatively simple epidermal covering.

Types of Stems.—There are many different types of stems, some of which are so different from the most common form that

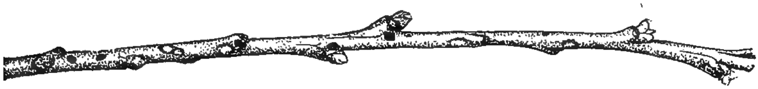

FIG. 8.—Stem with buds arranged alternately.

many people fail to recognize them as stems. Most stems are made up of nodes and internodes; the nodes marking the points from which the leaves and most new buds are produced. The leaves and buds are usually arranged alternately (Fig. 8), opposite (Fig. 9) or in whorls. In some few cases there is a single bud which is at the apex of the stem, as in palms and in some of the grasses and sedges. Some of the most common types of stems are as follows: (1) the *elongated* stem or *woody type* (Figs. 8 and 9), which is characteristic of our trees and firmer herbaceous plants. These stems are usually erect and present three very definite forms; (*a*) the *unbranched*, which is characteristic of the palms and corn; (*b*) the *deliquescent* type (Fig. 10), in which the primary stem subdivides into two or more branches, which in turn subdivide into numerous branches, as in the elm and oak; (*c*) the *excurrent* type (Fig. 11), in which numerous side branches are borne on a single primary stem, as in the pines. (2) The *acaulescent* type (Figs. 12 and 13), in which the internodes are very short, bringing the leaves into a close mass or rosette, as in the dandelion, turnip, radish and beet. (3) The *fleshy* type, which is made up largely of parenchyma tissue, such as the cactus. This type of stem serves for storage of water and food. (4) The *culm* or *grass* type (Fig. 14), which may be solid or hollow and is characteristic of the grasses and grains. (5) The *climbing* type (Figs. 32 and 33), which must cling to other objects for support, such as the morning-glory and many beans. The tendrils of cucumbers, pumpkins and grape vines are stems which are specialized for climbing by coiling around a support. The tendrils of the Virginia creeper are branched and have disk-like growths on the tips for attachment to walls. (6) The *decumbent* type, which starts erect and curves towards the ground at the tips, as in the blackberries and raspberries. (7) The *prostrate* or *creeping* type (Figs. 15 and 16), which lies on the ground, as in the ivy, strawberry, melons and creeping clover. (8) The *rhizome* or *rootstock*

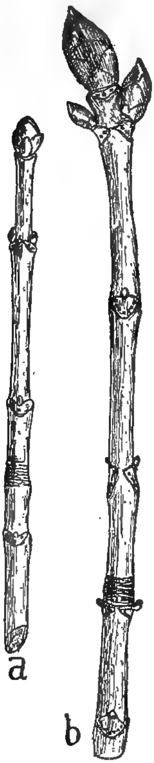

Fig. 9.—Stem with buds arranged opposite.

type (Fig. 17), which is an underground stem, such as we find in the May apple, Solomon's seal and Iris. This type can

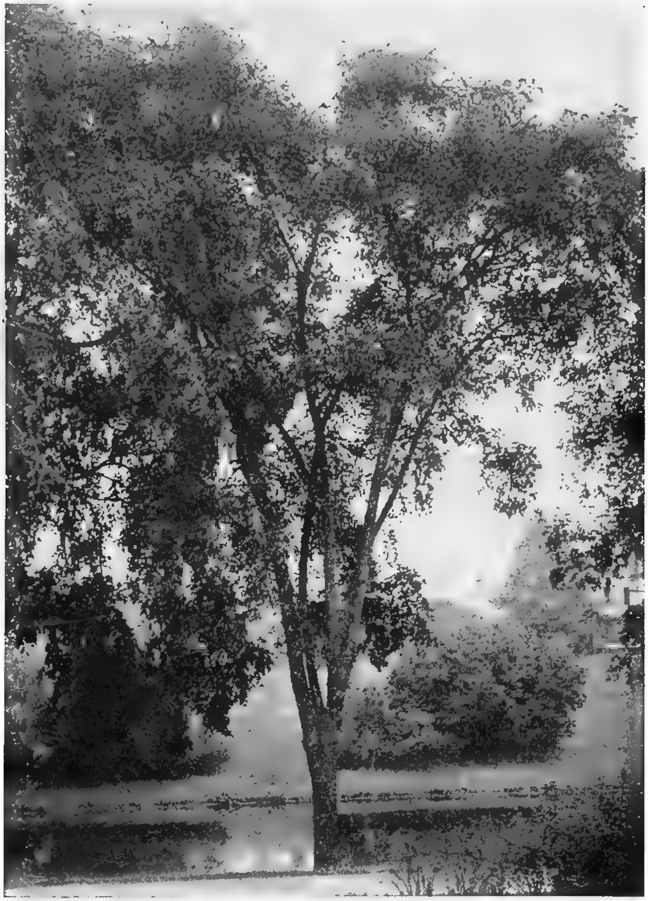

Fig. 10.—Deliquescent type of stem.

be readily distinguished from roots by the presence of nodes. Weeds with stems of this type are very difficult to destroy. (9)

The *tuber* type (Fig. 18), which is a short, fleshy underground stem, as the potato. This type serves for storage of reserve food materials. (10) The *bulb* type (Fig. 19), which is a very short stem with fleshy leaves and is usually produced underground. It is characteristic of onions, tulips, hyacinths and many other plants. This type also serves for storage of food materials.

FIG. 11.—Excurrent type of stem

(11) The submerged type or stems of plants that grow under water. Since they float in the water, the fibrous tissue is usually very poorly developed and the intercellular spaces very large. (12) The large thorns (Fig. 34) on the horny locust are modified stems.

Bulbs (Fig. 19) are specialized stems in which the internodes are very short and the leaves modified into thick, overlapping, scale-like structures. In the onion, lily, tulip and hyacinth

FIG. 12.—The acaulescent type of stem—dandelion.

bulbs the leaves are very evident, but in the Indian turnip or Jack-in-the-pulpit and crocus bulbs the stem is fleshy and the

FIG. 13.—The acaulescent type of stem—radish.

leaves or scales very much reduced. These two types are usually spoken of as scaly bulbs and corms. Plants that produce prominent bulbs usually produce few or no seeds. This is also true of plants that produce the tuber type of stems. Bulbs are very important in the propagation of many plants. The bulb-growing industry is very important in the production of many ornamental plants.

Buds are short, dormant stems bearing modified leaves and are capable of developing into leafy shoots (leaf buds) or flowers (flower buds). In most cases the buds are formed during the growing season and develop into shoots or flowers the following season. The outer leaves of the bud are usually scale-like and serve as a protective covering for the inner leaves or floral parts. These outer scales vary greatly in different plants, in some cases being very smooth with a varnish-like covering, in other cases with a gum-like covering, and in still other cases with a hairy covering. The protection is not directly

FIG. 14.—The culm or grass type of stem.

Fig. 15.—The creeping type of stem—strawberry.

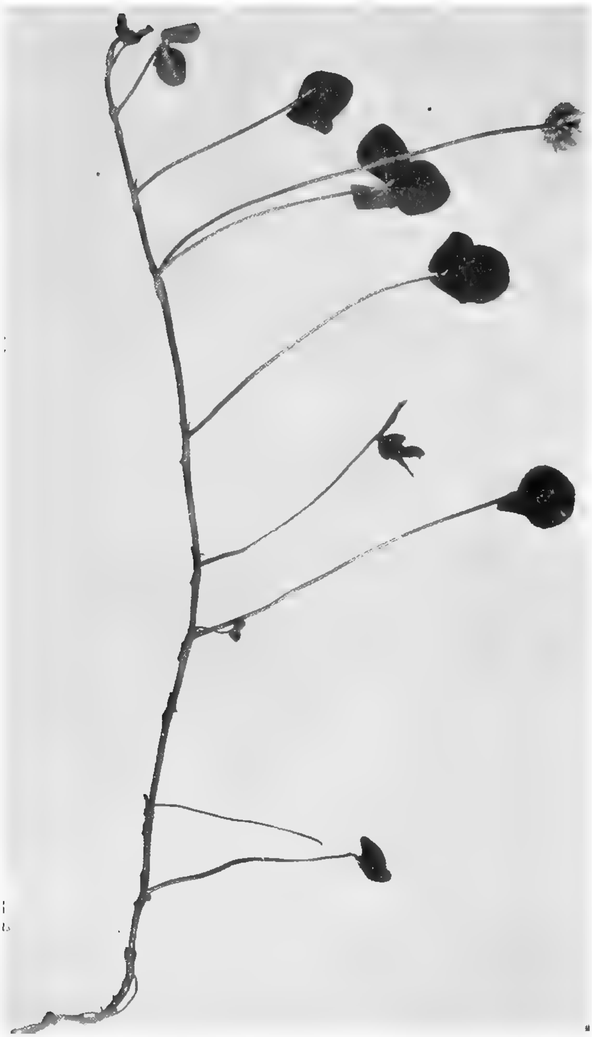

FIG. 16.—The creeping type of stem—creeping clover.

against extremes of temperature but against water, which would be injurious under almost any conditions. In some cases the

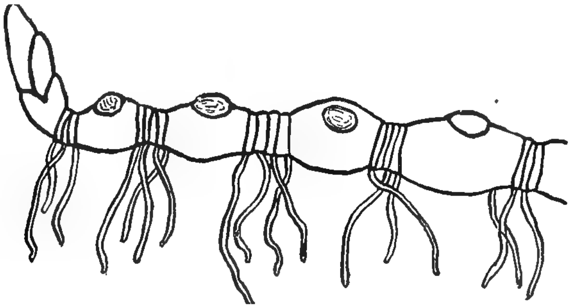

FIG. 17.—The rhizome or rootstock type of stem.

gum is bitter and may serve as a protection against animals which would eat them for food. When the leafy shoot elongates,

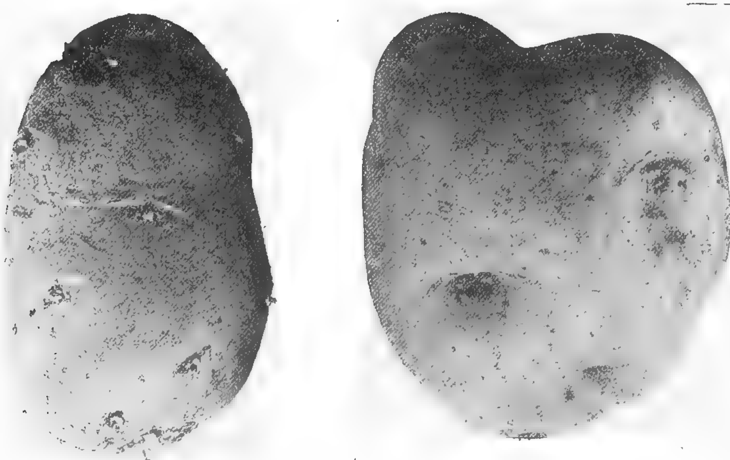

FIG. 18.—The tuber type—the potato.

the outer scales are shed and the leaves grow and expand very rapidly (Figs. 20 and 21). The scales and leaves are borne at the nodes of the stem. When the scales and leaves fall, there remain well-defined scars, and since the basal part of the stem elongates but very little as compared with the other parts, the scars at the base are very close together (Fig. 9). Therefore, the examination of these scars enables us to determine the annual growth of the shoot.

The arrangement of the buds on the shoot is subject to considerable variation; in some cases they are alternate, while in

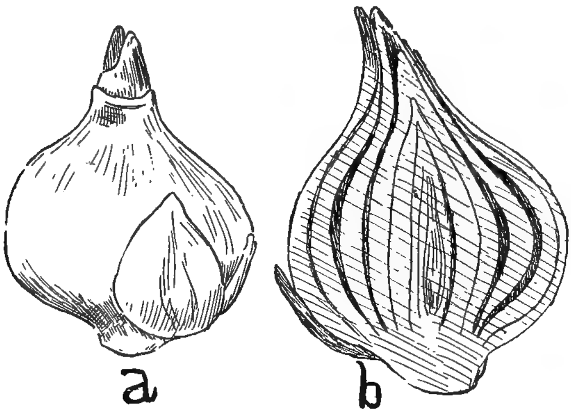

FIG. 19.—The bulb type—(*a*) tulip bulb; (*b*) same cut longitudinally to show basal stem and overlapping leaves.

others they are opposite (Figs. 8 and 9). In most cases they are borne in the axil or angle formed by the stem and leaf. Such buds are known as *axillary* buds. Additional buds that are borne above or to one side of the axil are *accessory*. The bud at the tip of the stem is known as the *terminal* bud and usually makes the most vigorous growth. Some plants produce two or more terminal buds. *Adventitious* buds are borne on other parts of the stems and in some cases on roots and leaves. Many buds perish, while others make such a slow growth that they are overgrown by the wood of the stem and cause what is usually known as "bird's-eye" wood. They are known as "dormant buds." Shrubby plants in which a very large percentage of the buds grow are frequently used for hedges. This hedge character is very prominent in such plants as the privet, the osage-orange and the barberry.

In most of our trees and shrubs the shoots reach their full length in a very short time, and the remainder of the growing

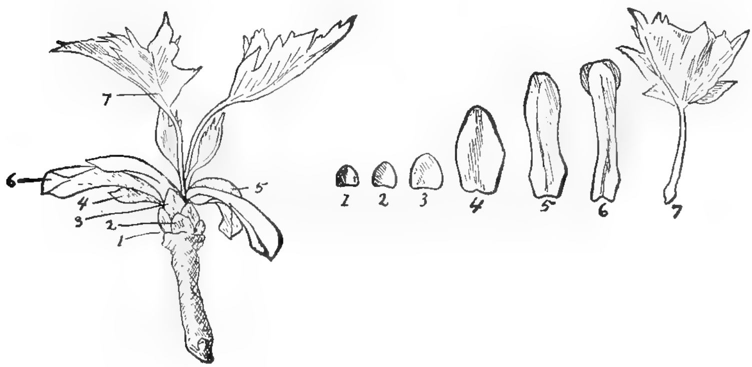

FIG. 20.—Bud, dissected to show scales and leaves.

season is devoted to thickening and hardening; this is known as "definite" annual growth. This is characteristic of most of our trees and shrubs in the North Temperate regions. In some other plants the shoots continue to lengthen and new leaves are produced throughout the season; as in the case of sumach, spice bush, roses and lilacs. This is known as "indefinite" annual growth. The terminal buds and tips of the shoots of this type of plant are frequently killed by frost. This makes it necessary for one or more of the lateral buds to develop as terminal buds the following season (Fig. 21).

Formation of Buds.—In most plants the buds undergo a period of rest. In our temperate climates they are usually forming during one growing season and rest until the next. These buds are so well developed during the formative period that each is practically a complete leafy shoot or flower in mini-

FIG. 21.—Lilac bud showing transition from scales to leaves. Also showing that the apical bud has been winter-killed and the next two lateral buds developed.

ature. Therefore, their opening and growth during the next growing season is extremely rapid.

Structure.—An examination of the structure of stems shows two types: the dicotyledonous and the monocotyledonous (Figs. 22 and 23). In the former we find the fibro-vascular bundles arranged in a circle, while in the latter we find them scattered throughout a pithy tissue or arranged in a circle about a hollow center. However, the true difference between these two types of stems depends on the structure of the fibro-vascular bundles.

Structure of the Dicolytedonous Stem.—A cross-section of a herbaceous stem shows four regions (Figs. 22 and 24): the *epidermis,* the *cortex,* the circle of *fibro-vascular bundles* and the *central* or *axis cylinder* of pith. In the case of the very woody stems we find the epidermis, the cortex, the fibro-vascular bundles which are V-shaped and very compact, and a comparatively small axis cylinder (Fig. 27).

The *epidermis* consists of a single layer of cells which forms a covering over the surface of the stem. These cells are cutinized and in young stems are very similar to the epidermal cells

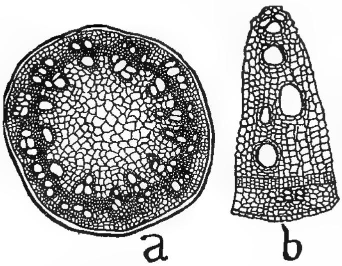

FIG. 22.—(*a*) Cross-section of dicotyledonous stem; (*b*) fibro-vascular bundle of same.

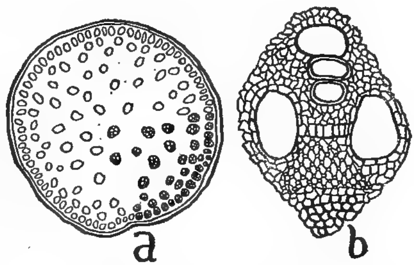

FIG. 23.—(*a*) Cross-section of monocotyledonous stem; (*b*) cross-section of fibro-vascular bundle of same.

of the leaf. They may vary somewhat in character, dependent on the kind of plant or the climatic conditions under which the plants are grown. The epidermis may be covered with trichomes or plant hairs, which are, in reality, a part of it, and are of the same general character as those found on the leaves.

The *cortex* is composed of parenchyma or collenchyma cells or both and lies just beneath the epidermis. These cells may contain chlorophyll and perform the functions of foliage. In old stems we frequently find elongated cells called sterome fibers or sclerenchyma fibers. The inner layer is known as the *starch sheath* and probably corresponds to the endodermis of the roots.

In most cases it is not well defined, and its function is not well understood, although it is supposed to serve for the conduction of carbohydrates.

The *fibro-vascular* bundles each consist of two parts which are separated by a layer of living cells known as the *primary meristem* or *cambium.* The outer part of the bundle is known as the *phloem* and is composed of bast fibers, sieve tubes and some other cells known as accompanying or companion cells. The inner

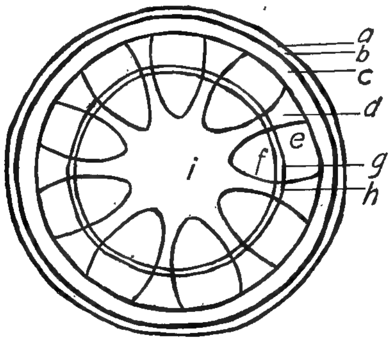

FIG. 24.—Diagrammatic drawing of section of dicotyledonous stem showing epidermis (*a*); cortex composed of collenchyma (*b*); parenchyma (*c*); medullary ray (*d*); fibro-vascular bundle composed of phloem (*e*); xylem (*f*); fibro-vascular cambium (*g*); interfibro-vascular cambium (*h*); and central axis composed of parenchyma (*i*).

part of the bundle is known as the *xylem* and is composed of wood fibers and tracheary tubes.

The *central axis* or pith is made up of parenchyma tissue, which varies greatly in amount in the various plants. It is sometimes very large, constituting the greater part of fleshy stems and serving for the storage of water and reserve food.

The Structure of the Monocotyledonous Stem.—A cross-section of a solid monocotyledonous stem, such as the corn, shows numerous fibro-vascular bundles scattered through a mass of parenchyma tissue, the entire structure surrounded by a hard, shell-like structure, which is made up of small, often dense, fibro-vascular bundles (Fig. 22). A cross-section of a hollow monocotyledonous stem, such as the wheat, shows the same general character, except that the bundles are arranged in a circle. The fibro-vascular bundle is made up of the same tissue as the bundle of the dicot stem, except for the meristematic tissue or cambium, which is present in the young but absent in the old parts of the bundles. The growth in a fibro-vascular bundle of this type is restricted to the youngest or terminal part. Therefore, after reaching a certain period in their development, monocotyledonous stems cease to increase in diameter and grow in length only.

The Growth of the Dicotyledonous Stem.—The growth of the dicotyledonous stem involves: (1) cell divisions in the meristematic regions resulting in the formation of many new cells; (2) the enlargement of cells, and (3) the differentiation of the cells into the various tissues to which we have already referred (Chapter II). The details of this process are as follows: The *primordial meristem* (Fig. 25) is a mass of undifferentiated cells at the top of a growing shoot. They are the actively growing parenchyma cells which give rise to all the other tissues of the stem. The first differentiation of the mass of cells gives rise to three more or less distinct groups of cells just back of the growing point. They are the *protoderm, ground meristem, procambium* and constitute the complete *primary meristem.* Each of these three groups of cells gives rise to other groups of cells as follows:

The *protoderm* is gradually transformed into the epidermal structures previously referred to. The *procambium* is gradually transformed into the *fibro-vascular bundles,* which are composed

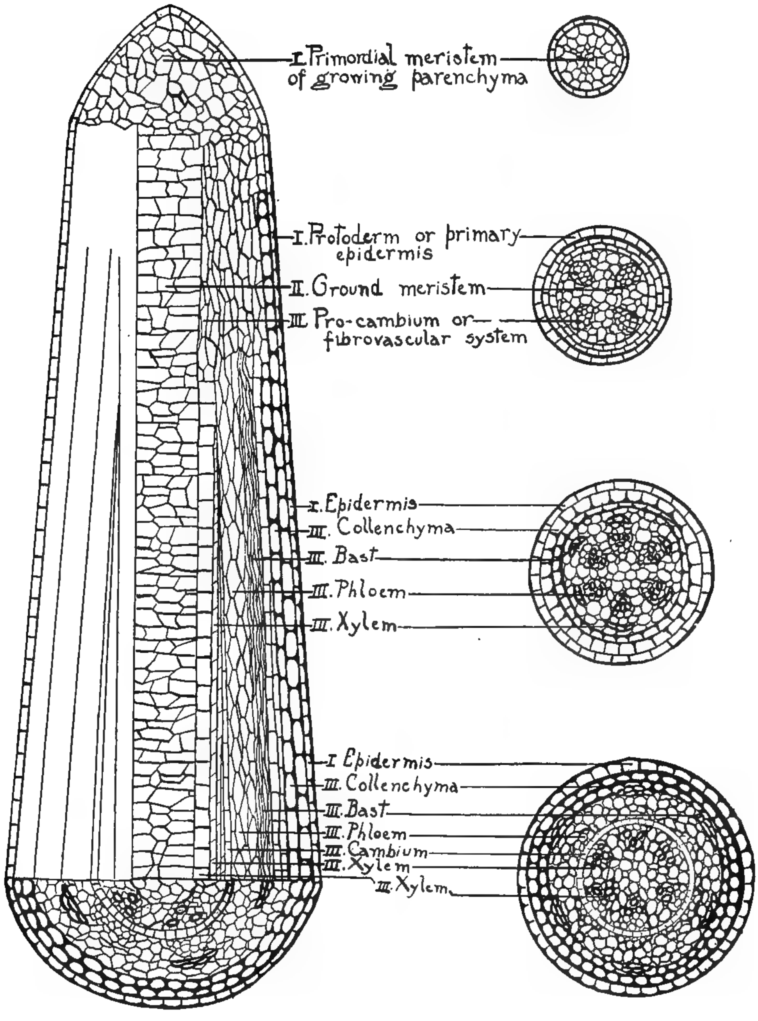

FIG. 25.—Diagrammatic drawing of tip of dicotyledonous stem showing the development of the tissues. (Adapted from Stevens' Plant Anatomy.)

of many tissues. The *ground meristem* is differentiated into:

(*a*) *Primary cortex*—a zone of cells which are mostly parenchyma and lying exterior to the procambium.

(*b*) *Pericycle*—extending from the primary cortex to the phloem.

(*c*) *Primary medullary rays*—lying between the fibro-vascular bundles.

(*d*) *Medulla*—or pith forming the central axis.

Therefore, it will be readily seen that the *primordial meristem* and the *cambium,* which is, in reality, a part of it, and derived from it, are the growing tissues of the plant. The former forms a cap at the tip of the shoot and the latter a cylindrical sheath of actively dividing cells between the phloem and the xylem. All other tissues, except those hereafter mentioned, cease to grow, become fixed and are known as fixed or permanent tissues. The exceptions are the *cork cambium* or *phellogen,* from which cork is developed, and the *interfascicular cambium,* which unites the *fascicular cambium* of the bundles, thus making a complete ring. The *fascicular* and *interfascicular cambiums* are usually spoken of together as the *cambium.* The *interfascicular* and the *cork cambium* are frequently referred to as the *secondary cambium* (Fig. 26). It will be readily seen that the stem elongates by the growth and division of the cells of the *primordial meristem* at the tip. The increase in diameter is due to the growth and cell division of the *cambium* and *secondary cambium,* hence often called secondary meristem. All other tissues soon lose the power of cell division.

The *cambium,* as usually spoken of, is composed of two parts, the *fascicular* part lying between the xylem and phloem, giving rise to new elements of the bundles, and the *interfascicular* part, which connects the fascicular parts and gives rise to the *medullary* rays (Fig. 23). The cambium is made up of very delicate, active parenchyma cells, which divide longitudinally and parallel to the surface of the stem (*i.e.,* tangentially) with occasional longitudinal divisions at right angles to the surface of the stem (*i.e.,* radially) and with occasional cross-divisions. As a result of these tangential divisions new layers of cells are added to the fibro-vascular bundles, and the diameter of the stem gradually increases. Most of these layers are added to the xylem, which grows more rapidly than the phloem. However, in this latitude the xylem ceases to grow about the middle of August, but the phloem continues to grow until November. These new layers of cells are of the same character, but undergo differentiation to form the various tissues of the xylem and phloem which have been already described. We are unable to explain why some of these cells

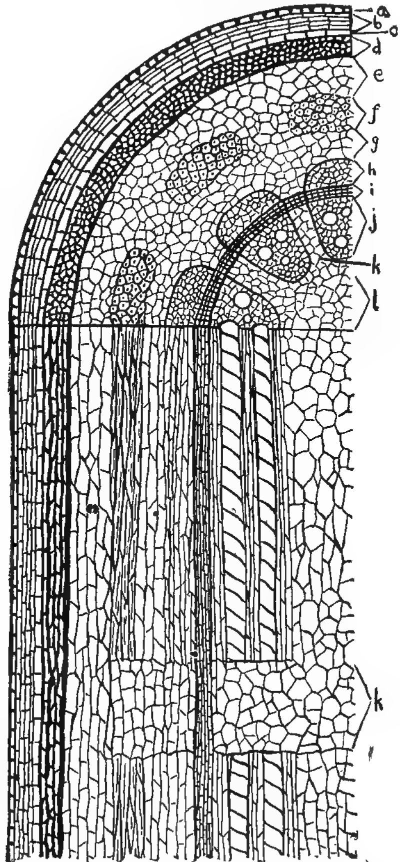

FIG. 26.—Diagrammatic drawing of dicotyledonous stem showing relative location of the tissues and systems. The epidermal system composed of the cork (*a*, *b*), the phellogen or cork cambium (*c*), and the collenchyma (*d*); the cortex composed of parenchyma (*e*, *g*) and the bast (*f*); the fibro-vascular system composed of the phloem (*h*), the cambium (*i*) and the xylem (*j*); the medullary rays (*k*), and the pith (*l*).

form one kind of tissue while others form another kind.

In cross-sections the fibro-vascular bundles appear to be wedge-shaped. As these wedges increase in size, new or secondary medullary rays are formed from the interfascicular cambium, and, therefore, the older the stem the more numerous the fibro-vascular bundles. These bundles and rays are very evident on the cut end of a woody stem. Along with the growth from the fascicular cambium there is a corresponding growth from the interfascicular cambium. In fact, the growth of the fascicular and interfascicular cambium is and must necessarily be uniform. In addition to this growth, the interfascicular cambium sometimes forms new fibro-vascular bundles, which in cross-section appear as narrow strips that split the primary medullary ray.

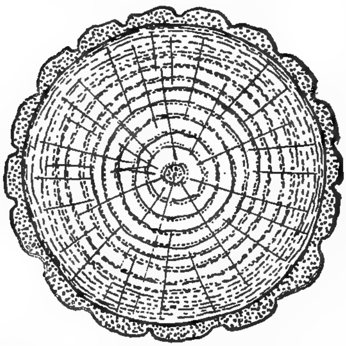

FIG. 27.—Cross-section of dicotyledonous woody stem showing annual rings, medullary ray and epidermal system.

Annual Rings.—The cross-section of a woody, perennial stem shows a number of well-defined rings (Figs. 26 and 27). Since the rings are usually formed at the rate of one per year and are a good index to the age of the tree, they are called annual rings. They are due to differences in growth in the early and late part of the growing season. In the early part of the growing season the tracheary tubes are numerous and have large cavities and thin cell walls. As the season advances they decrease in number and size, and the walls become thicker; the wood fibers undergo a corresponding increase in number throughout the season. In brief the conducting cells predominate in the spring growth, and the strengthening cells predominate in the fall growth. These rings are very evident on the cut end of a woody stem.

Medullary Rays.—The cross-section of a woody perennial stem shows a number of lines radiating from the central axis; they are the *medullary rays* and are derived from the interfascicular cambium (Figs. 26 and 27). Some extend from the pith through both xylem and phloem, while others originate at various points and extend through a part of the phloem only. The former are known as *primary rays* and the latter as *secondary rays*. They consist of thin layers of thin-walled (parenchyma) or more or less thick-walled cells. They are the important factors in decorative woods, especially in quarter-sawed oak. The direction of the sawing gives various views. If the log is sawed so that the surface of the board is parallel to the ray, it is said to be quarter-sawed, and the tissues of the ray form artistic markings. If sawed at any other angle, the figures are much less artistic.

The Cork Cambium (Fig. 26).—The growth of the cambium causes an increase in the diameter of the stem and results in an increasing tension of the primary cortex, and would eventually cause a splitting of the outer layer of the stem if it were not for the growth and cell division in this region. In the woody perennials this activity is primarily in the cork cambium or phellogen. This originates in tangential division of epidermal cells or in the cells just below the epidermis. In either case the result is a cork cambium before the end of the first year's growth. This cork cambium or phellogen undergoes both radial and tangential cell division, producing cork cells to the outside and a smaller number of thin-walled parenchyma cells to the inside called the *phelloderm.* All these new tissues outside the cork cambium are called the *periderm.* The walls of the cork cells become suberized and are, therefore, impervious to water. They eventually die and are gradually sloughed off as old bark, exposing the inner younger cork growth beneath. This sloughing or peeling off of the bark is characteristic of most forest trees. Many trees are roughly corrugated, the bark peeling off in such small fragments as to be scarcely noticeable, as in the oaks, while in others it peels off in large pieces, as in the case of the shag bark hickory. The bark of the sycamore cracks and comes off in fragments, while the bark of the birch peels off like paper.

Fig. 28.—Trunk of a birch tree showing the large lenticels.

The *suberization* is brought about by chemical changes in the cellulose and the addition of suberin layers to the suberized walls, or by the addition of suberin layers only. *Suberin* is waxy in character, very similar to cutin (page 78) and is water-proof. Of course, the suberized or water-proof epidermis or cork over the surface of the stem is a very great protection against the escape of water from the stem when in a dry atmosphere and also against the absorption of water when subjected to an undue amount of moisture. But there is a provision for aeration of the tissues through *lenticels*

(Fig. 28). These structures are developed from the stem stomata, which will be described more fully in connection with the structure of the leaf (page 78).

The *stomata* are openings into intercellular spaces within the

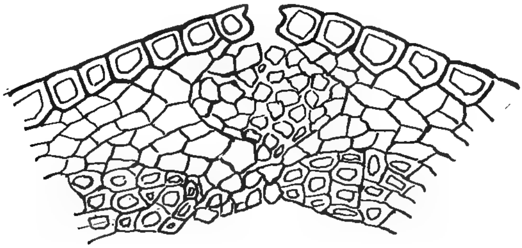

FIG. 29.—Cross-section showing early stage in the development of a lenticel.

leaf, stem or other part of the plant and permit of the free access of air into the interior. The cells just beneath the stomata of the stem increase in number, become corky and finally rupture

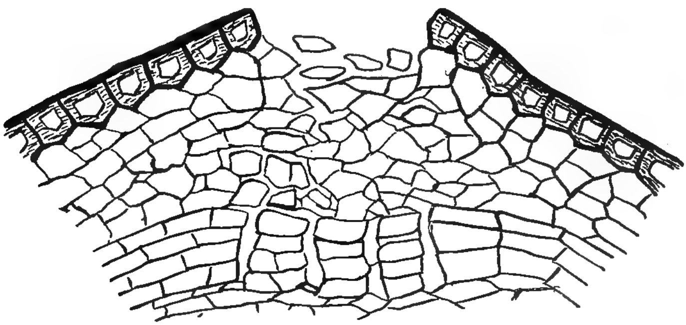

FIG. 30.—Cross-section showing late stage in the development of a lenticel.

the epidermis (Figs. 29 and 30). They continue to permit the free access of air to the interior of the stem but prevent the passage of water. These lenticels are very easily recognized as small specks on young woody stems and sometimes are very prominent on the older stems, especially the birch trees.

Heartwood and Sapwood.—As tree trunks increase in age and thickness, the cells in the center become less and less active and gradually die. Successive layers of cells die until we have the large cylindrical core of dark-colored cells, which are known as the heartwood. The fact that hollow trees live and thrive proves that the heartwood is of little or no value to the tree, except for support. The zone of lighter-colored wood just outside

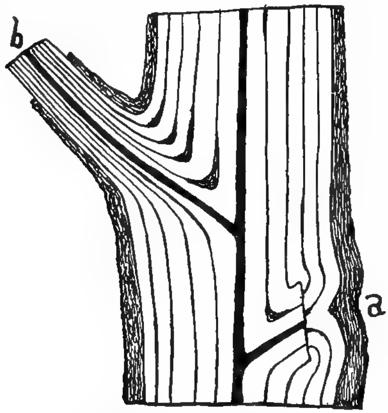

FIG. 31.—Longitudinal section of stem showing origin of branches; proper method of pruning (*a*) and improper method of pruning (*b*).

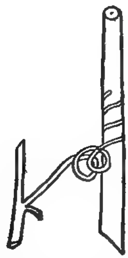

FIG. 32.—Tendril type of stem.

the heartwood is known as the sapwood. Both the sapwood and the heartwood contain a considerable amount of water.

Branching of the Stem.—The new lateral growth, whether shoot or leaf, originates in the primary meristem. The cells divide rapidly and cause a slight elevation on the surface. This is known as the *endogenous* origin and is the characteristic method of forming new shoots (Fig. 31). It is quite different from the origin of branches of the roots (page 68). Many of these exogenous growing points (buds) become dormant and completely overgrown by the other tissues. They are the causes of the so-called "bird's-eye wood." Others may lie dormant for many years and then be stimulated into activity.

The Growth of the Monocotyledonous Stem.—The growth of this type of stem also involves (1) cell division, (2) cell enlargement and (3) cell differentiation into tissues. However, the position of the meristem or cambium and its behavior are quite different. From the arrangement of the bundles it will be readily seen that there can be no cambium ring (Fig. 23). The cambium is active only at the tips of the bundles and for a short time in that part of the bundle just above the node. The increase in diameter of the stem is due primarily to the enlargement of the cells of the permanent tissues. Of course, such a stem cannot increase in diameter indefinitely as in the case of the dicotyledonous stem. There are some few exceptions to this which we will not discuss at this time. The fibro-vascular bundle of the Indian corn (Fig. 23), which may be taken as a type of the monocot stem; the central part is composed of tracheary tissue, with a mass of sieve tissue on the side nearest the surface of the stem, all of which is surrounded by fibrous tissue.

Functions of Stems.—The primary functions of the stems are the support of the foliage, flowers and fruits in the air and sunshine and the *transportation* of food materials and foods from one part of the plant to another. We will learn a little later (Chapter V) that the foliage has a very definite relationship to the air for the exchange of atmospheric gases and to the sunlight from which it obtains its energy for work. Therefore, the character of the stem must be such as to bring about these relationships. We will also learn (Chapter IV) that the plant obtains its water and many food materials from the soil. Therefore, there must be some system for the transfer of food materials and food products. These functions of support and transportation are performed by the stem.

The secondary functions are: (1) *photosynthesis* by green stems in the same manner as the leaves (page 195). This is of secondary importance in most plants, but is a primary function in such plants as the cactus, in which the leaves are of no consequence. (2) For the *storage* of water and reserve foods, as in the case of the cactus, the tuber of the potato and the fleshy bulbs. (3) For *climbing*, as in the case of the morning-glory,

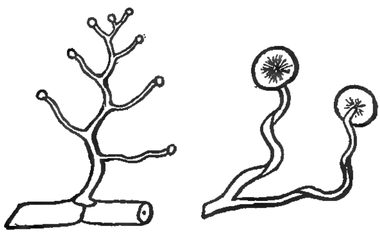

FIG. 33.—Ivy holdfast type of stem.

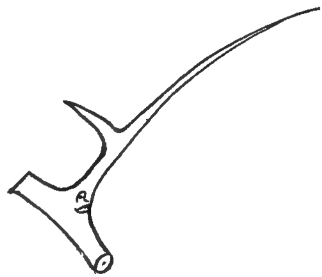

FIG. 34.—Thorn type of stem.

the grape and some of the ivies (Figs. 32 and 33). (4) As *thorns* (Fig. 34), in the case of the honey locust and hawthorn. (5) For *reproduction*, as in the case of many underground stems, the willows, grapes and many other plants. The tendency of many plants to reproduce by means of stems is utilized by the growers. The tubers, or underground stems of potatoes, are always used in the growing of this crop. Grapes, roses, geraniums, begonias, carnation, privet, willows and a whole host of other plants are very generally propagated by means of cuttings. Bulbs are also used for the growing of many plants. The stems are also used in grafting and budding (page 103).

LABORATORY EXERCISES.

Exercise 1. Dicotyledonous Stem. Examine thin cross-sections of stems of Begonia or Geranium. Note the epidermis, fibro-vascular bundles and ground system or pith. Note the number of layers of epidermal cells; the cuticularized outer cell walls of the outer layer of cells; the trichomes; the arrangement of the fibro-vascular bundles; the phloem and xylem parts of the bundles. Determine so far as possible all the tissues that can be recognized in the cross-section of the stem. Give special attention to the fibro-vascular bundle.

Exercise 2. Examine cross-sections of one-, two- and three-year-old stems of basswood and note the number of fibro-vascular bundles, medullary rays, pith and formation of external covering.

Exercise 3. Examine thin sections of bark or older woody stems and note the cork cells.

Exercise 4. Monocotyledonous Stem. Study the arrangement and structure of the fibro-vascular bundles in cross and longitudinal sections of stems of corn. Locate the tissues so far as possible.

Exercise 5. Study the arrangement of the bundles in cross-sections of a grass or grain plant.

Exercise 6. Examine the stems of several trees. Note the arrangement of the buds and leaf scars. Also note the lenticels.

Exercise 7. Examine a cross-section cut through the lenticel and note the character of the cells.

Exercise 8. Examine several types of bulbs, including onion, hyacinth, tulip, crocus, and such other plants as may be available. Note the short stem or axis and the scales.

Exercise 9. Examine two or more types of underground stems, including the tuber of the potato. Note the nodes, internodes, buds and lenticels.

Exercise 10. Examine the end of a large woody stem and note annular rings, medullary rays and pith.

Exercise 11. Select a large bud from a tree and split lengthwise. Compare with a bulb.

Exercise 12. Select a large bud and dissect carefully, comparing the outer scales and inner leaves.

CHAPTER IV

ROOTS

THE **root** system is the part of the plant which is usually located in the soil and serves primarily for anchorage and for the absorption of water and mineral food materials which are in solution in the water. However, the location below the ground is not a distinctive character of roots, for it must be remembered that some plants have roots above the soil and that some plants have underground stems. A much better distinctive character is that roots are not divided into nodes and internodes, as in the case of stems. Therefore, stems usually branch regularly from the nodes, while the roots branch very irregularly.

Types of Root.—Roots may be very generally divided into two groups: the *fibrous* and the *fleshy roots* dependent on their character and also into *primary* and *secondary* roots dependent on their location. The *fibrous roots* (Figs. 35 and 37) are more or less woody and are characteristic of most of the higher plants. In the case of large plants the roots are usually very large and very woody. The roots of some trees produce a beautiful wood, which is highly prized for cabinet-making. The *fleshy roots* (Figs. 36 and 37) contain the woody elements or fibro-vascular bundles, but they also contain large amounts of parenchyma tissue and therefore serve for storage of water and other food materials. They are always associated with fibrous roots, which serve primarily as organs of absorption. Turnips, radishes, beets and similar plants have the fleshy root systems. Some fleshy roots, such as the sweet potato and dahlia, resemble tubers and are sometimes referred to as tubers, but they must not be confused with the tuber of the white potato, which is a fleshy underground stem. Fleshy roots are used extensively for food.

The *primary root* is the first one that emerges from the seed. The *secondary roots* are those which arise from the primary

FIG. 35.—A grass plant showing the fibrous root system.

FIG. 36.—Carrot showing fleshy roots.

root. There are also many other kinds of roots to which special names have been given, such as: (*a*) *adventitious roots*, which are developed from runners, as in the case of the strawberry. (*b*) *Aerial roots*, which grow from parts of the stem above ground and may or may not reach the soil. They are produced abundantly by the poison ivy and the trumpet creeper and serve for climbing (Fig. 38). Some aerial roots grow downward to the soil and serve as braces or props, as in the case of corn (Fig. 39). (*c*) *Roots of epiphytic* plants having no connection with the soil but which cling to trees or other objects and derive their nourishment from the air. They are very abundant in the moist tropics and have coverings of cells which are especially adapted for the absorption of water from the air. (*d*) *Roots of parasitic* plants, which penetrate other plants and feed upon

FIG. 37.—Sweet potato showing both fibrous and fleshy roots.

their juices. The mistletoe and dodder (Fig. 40) are excellent examples. Plants with roots of this kind are sometimes very injurious to the plants on which they grow. (*e*) *Water roots* are formed on many floating plants, such as the duckweed. Willows sometimes produce a specialized root system, which spreads out in the water. The stems of many plants which grow normally in the soil will produce roots if submerged in water or wet sand. The roots of most plants do not produce buds, and this is one of the distinctive characters between roots and stems, but some

FIG. 38.—Aerial roots of poison ivy.

plants produce adventitious root buds in great abundance, which are important factors in reproduction. The root of the sweet potato produces great numbers of buds, which give rise to the slips or small plants which are used for setting. Some trees,

FIG. 39.—Corn plants showing the aerial roots.

especially the poplars, produce buds and shoots from the roots and are sometimes very troublesome.

Functions of Roots.—The primary function of roots is no doubt the absorption of water and the mineral food materials that are dissolved in it. The most important secondary functions are for anchorage in the soil or attachment to other objects, for storage (Figs. 36 and 37) and for climbing (Fig. 38). The roots of most, if not all, plants serve to a greater or less degree for storage, but this function is especially evident in the fleshy roots of such plants as the sweet potato, carrot, parsnip, radish, turnip and beet. The fleshy roots may be the *conical,* which are largest at the top and gradually taper downward to a point, as in the carrot, the *napiform* or *turnip-shaped,* which are large at the top but do not taper, as in the turnip, and the *fusiform* or *spindle-shaped,* which are largest in the middle and taper in both directions, as in some radishes. Some fleshy roots, such as the sweet potato (Fig. 37) and dahlia, are produced in bunches or fascicles.

The stored food materials are for use at some future date, usually for the formation of flowers and fruits but sometimes for

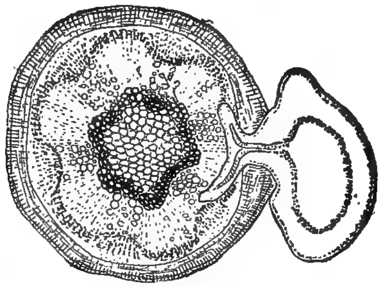

FIG. 40.—Cross-section of stem showing dodder attached by haustoria or parasitic root.

the direct production of new plants. In the radish the flowering stalk is produced the same season that the root is produced; but turnips are usually kept over for a year and produce their flowering stalks the second season. The sweet potato and dahlia roots produce new plants directly. This storage of foods in the roots corresponds to the storage of foods in the stems and leaves (see page 74). The value of roots as food for man and other animals depends on the character and amount of stored food, upon the small amount of fibrous tissue and the absence of injurious substances. Reproduction is a function of the roots in the case of such plants as the sweet potato and the poplars to which we have already referred. However, the production of stems from roots is much less frequent than the production of roots from the stems (page 56). Some climbing plants, such as the trumpet creeper and the poison ivy, produce roots which serve as holdfasts and enable them to cling to trees, walls and other objects. The climbing roots should not be confused with stems which also serve this function (page 62).

Structure of Roots.—The root consists of the same kinds of

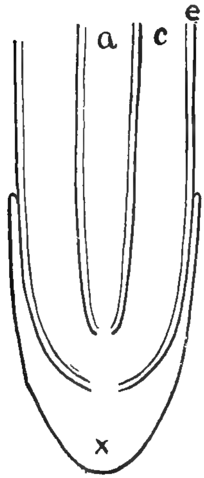

FIG. 41.

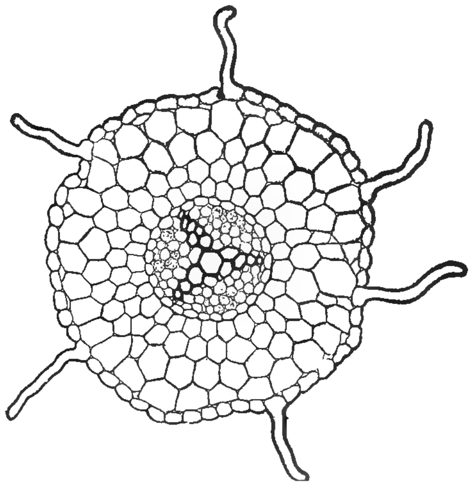

FIG. 42.

FIG. 41.—Diagrammatic longitudinal section of root tip showing: (*a*) axis cylinder; (*c*) cortex; (*e*) epidermis; (*x*) root-cap.

FIG. 42.—Cross-section of root tip showing cellular structure and root-hairs.

tissues as are found in the stem, but the arrangement is somewhat different. There are four well-defined regions: the *axis cylinder* in the center, which is surrounded by the *endodermis;* then a zone known as the *cortex,* and finally the outside covering or *epidermis.* On the tip of the root is the *cap* (Figs. 41 and 42), a loose but well-defined mass of cells forming a protective covering over the growing point.

The *axis cylinder* consists of the xylem and phloem, which are arranged radially and alternate. The xylem is in the center of the root with branches that project outward towards the surface, giving it a star-like appearance in cross-section. The phloem lies between these projections. The tissues of which they

FIG. 43.—Seedling showing soil held by root-hairs.

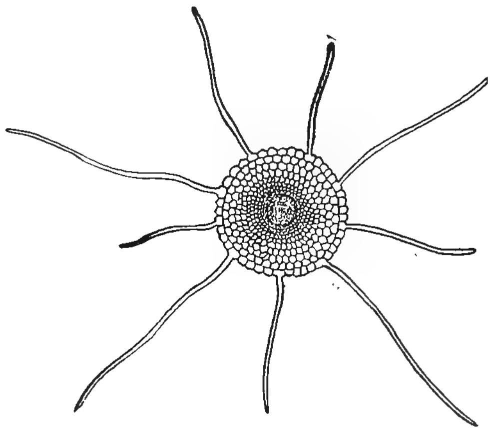

FIG. 44.—Cross-section of rootlet showing root-hairs.

are composed serve the same functions as in the stems. In the older roots, a cambium is developed which gives rise to secondary xylem and phloem as shown in the diagram. The *endodermis* is a more or less definite sheath of starch-bearing cells surrounding the axis cylinder and probably corresponds to the starch sheath of the stems. The *cortex* is a broad zone of parenchyma cells which frequently serve for storage of reserve food materials,

5

especially in the fleshy roots. The epidermis is a layer of surface cells which give rise to numerous *root-hairs* or *trichomes* (Figs. 43, 44, 45 and 46). Each root-hair arises from a single epidermal cell and in fact is an extension or part of the cell. They are very numerous and very rich in protoplasm and are always located in a zone just back of the tip. New hairs are being

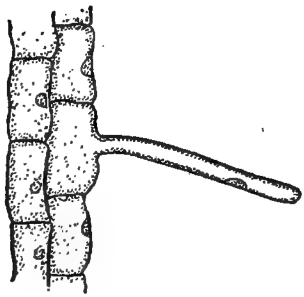

FIG. 45.—Showing attachment of root-hair to epidermis.

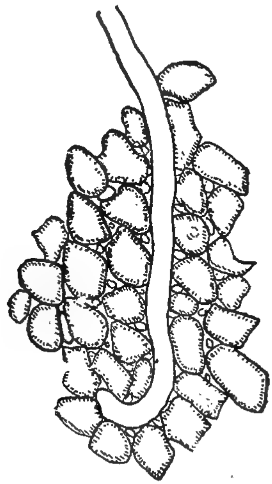

FIG. 46.—Showing relation of root-hair to particles of soil.

formed towards the growing tip, while those remote from the tip are gradually dying. The living root-hairs penetrate between the fine particles of soil and serve for the absorption of water and such other food materials as are dissolved in it. The *root-cap* is a mass of cells, which covers and protects the underlying delicate cells as the growth pushes the tip through the soil. It is a part of the epidermal system, and the outer cells are gradually worn off and new ones produced from within. The epidermal cells of the very young roots are not cutinized, as in the case of leaves and stems, but the epidermal cells of the older roots are cutinized to a greater or less degree.

Growth.—The most active cell growth and cell division is at the tip of the root just within or back of the root-cap. Back of this point for a distance of 2 to 4 mm. the cell divisions are less rapid, but the cell elongations are very pronounced. It is the zone of rapid elongation (Fig. 47). The growth of the root tip is accompanied by the addition of cells to the inner surface of the root-cap, thus compensating for those on the outer surface, which are gradually destroyed as the tip advances through the soil. In the older roots a *cork cambium* and a bark covering are formed. This is very common in the perennial shrubs and trees. These old roots have practically lost the power of absorption.

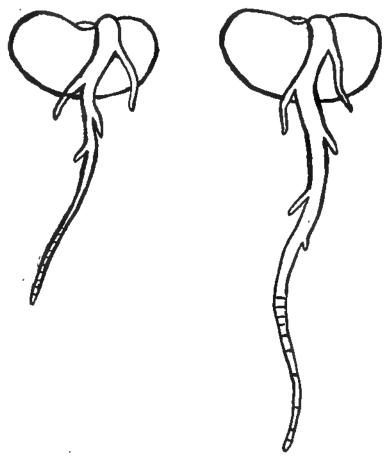

FIG. 47.—Germinating beans showing region of elongation.

Branching of Roots.—The new root branches originate quite differently from the stem branches (page 54). They begin in the cells just outside the xylem, push through the cortex, gradually absorbing the older tissues and finally come to the surface (Fig. 48). This is known as the *endogenous* method of branching.

Absorption.—The root-hairs are formed with the growth and elongation of the roots and are always rich in protoplasm. In brief, they are ideal structures for the taking in of water and the materials which are dissolved in it, by *osmosis*. They penetrate between the particles of soil and are in contact with the soil water in which many minerals are dissolved (Fig. 46). Some of these minerals may be necessary for growth and others may be unnecessary, or even injurious to the plant. Water and more or less of these minerals are transferred from cell to cell to other parts of the plant for future use by processes which will be explained later (page 162).

FIG. 48.—Longitudinal diagram of root, showing origin of branches.

Distribution of Roots.—Since one of the primary functions of roots is the taking in of water nd other food materials, they must be distributed in the soil in such a manner as to perform this function to the best advantage. Some plants may be called shallow feeders and have their root systems spread out near the surface of the soil, while other plants are deep feeders and have their root systems extending down deep into the soil. The distribution of the root system is more or less characteristic of most plants but is influenced to some extent by the amount and distribution of soil moisture and food materials. The root system is very extensive; when a plant is pulled from the soil, most of the roots are torn off, but if it is removed very carefully and washed, so as to retain all the minute branches, the total length may amount to several hundred yards. The distribution and extent of the root system will receive further consideration in Chapter XIII.

LABORATORY EXERCISES.

Exercise 1. Types of roots. Examine the fibrous roots of corn, grass and clover; the fleshy roots of sweet potatoes, radishes and carrots, and note their characters.

Exercise 2. Origin and position. Examine a number of germinating grains of corn and note origin and order of formation of the roots.

Exercise 3. Examine specially prepared longitudinal sections of root tip of corn, onion or other plant. Note the axis cylinder, endodermis, cortex, epidermis and root-cap. Also note the size and shape of the cells in various parts.

Exercise 4. Examine a cross-section of a root and note the same points (excepting root-cap).

Exercise 5. Examine the root-hairs from roots of corn, okra or other seeds that have been germinated between sheets of wet blotting paper.

Exercise 6. Germinate seeds in loose soil; wet the soil thoroughly; pull the seedlings carefully. Note the amount of soil clinging to the roots.

CHAPTER V

LEAVES

The **leaves** constitute the foliage of the plant. They are the expanded part and have a very definite relation to sunlight and air. They are naturally the most prominent part of the plant and together with the flowers and fruits attract the greatest amount of attention.

Parts of the Leaf.—The parts of the leaf (Fig. 49) are the blade or lamina, which is the expanded part and is supported by a mid-rib and numerous secondary ribs and veins. The leaf is usually attached to the stem by means of a petiole which is prolonged into the mid-rib. Some leaves do not have petioles and are called *sessile* (Fig. 49). At the base of the petiole there are often two small more or less leaf-like structures known as *stipules;* they may be permanent or may fall very soon after the leaf unfolds.

The *stipules* are extremely variable in character and are very important in writing descriptions of plants. The *free* type is separate from the petiole and may be persistent or may fall early; the *adnate* type is attached to the petiole and is characteristic of the clovers. The *ligule* is the short, thin, projecting membrane at the top of the sheath of the leaves of the grass plants (Fig. 50).

Types of Leaves.—There are a great many types of leaves, dependent on character of venation, form, thickness and other characters. These variations in type are usually correlated with the relationship of the leaf to air and sunlight or to some special function which the leaf may serve. Leaves may be divided on basis of venation into net-veined, in which the veins interlace, and parallel-veined, in which the primary veins run more or less parallel (Fig. 49). The net-veined are of two types, those in which the secondary veins arise from the mid-rib and are known as pinnately veined (Fig. 49) and those which have three, five, seven or nine primary veins or mid-ribs giving rise to the sec-

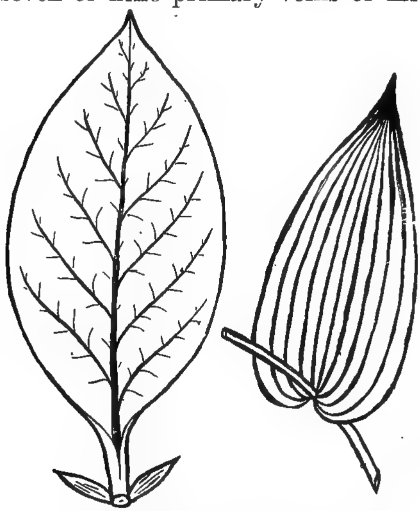

Fig. 49.—Typical net-veined leaf and typical parallel-veined leaf.

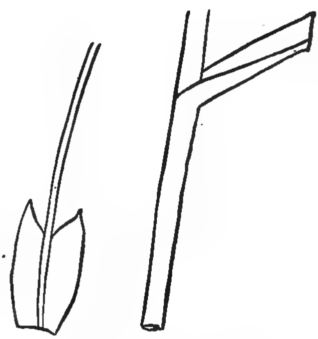

Fig. 50.—Stipules of clover and grass leaves.

ondaries (Figs. 51 and 52). The parallel-veined are also of two types, those in which the primaries run from base to tip, as in the corn and Iris, and those in which they run from base to the margins, as in the pickerel weed and calla. Leaves may also be divided on a basis of form into (*a*) simple leaves (Fig. 49) with but one continuous blade and (*b*) compound leaves, which have two or more blades or leaflets attached to a common petiole. The compound leaves are of two types, the pinnately compound (Fig. 53), in which the leaflets are attached at various points along the petiole from base to tip, and the palmately compound (Fig. 54), in which the leaflets are attached at the tip of a common petiole.

The simple leaves are variously designated as cordate or heart-shaped, cuneate or wedge-shaped, deltoid or delta-shaped, elliptical or ellipse-shaped, hastate or halberd-shaped, lanceolate

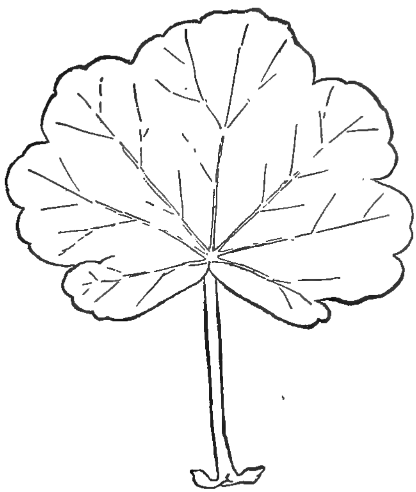

FIG. 51.—Palmately veined leaf.

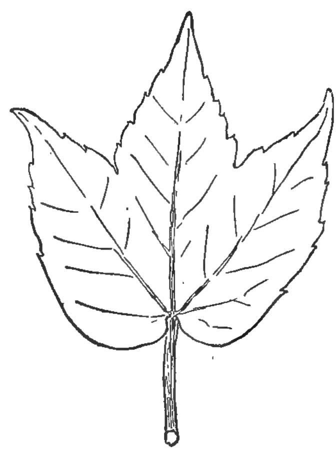

FIG. 52.—Palmately veined leaf.

or lance-shaped, orbicular or circular, oval or egg-shaped, reniform or kidney-shaped and sagittate or arrow-shaped. The margins of the leaf may usually be described as entire or smooth, serrate or saw-toothed, dentate or toothed, or lobed. All gradations may be found from the slightly lobed, through the more deeply lobed to the compound leaves.

Functions of Leaves.—The most important function of the leaf is the making of carbohydrates, which is the first step in the making of food materials of all kinds. These carbohydrates, sugars and starches, are made from the water which has been taken up by the roots and transported to the leaves and the carbon dioxide which is taken directly from the air. The energy for this work is the sunlight, which is absorbed by the chloro-

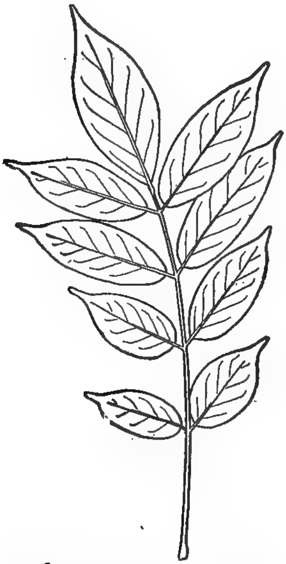

FIG. 53.—Pinnately compound leaf.

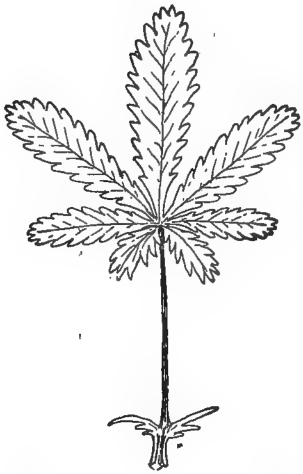

FIG. 54.—Palmately compound leaf.

phyll. The process is known as *photosynthesis,* which will be described later (page 195). This process may be expressed by the following formula:

$$\underset{\text{(Water)}}{5H_2O} + \underset{\text{(Carbon dioxide)}}{6CO_2} = \underset{\text{(Sugar)}}{C_6H_{10}O_5} + \underset{\text{(Oxygen)}}{6O_2}$$

It involves the transpiration or giving off of water, the exchange of atmospheric gases and the absorption of sunlight. Therefore, it will be readily seen that the leaves must have a very definite relationship to both air and sunlight. Looking upward into the top of a tree, it will be seen that the leaves are on or near the tips of the shoots and form a canopy supported by the branches as a framework; or, looking down on the tree, it will be noted that there is very little overlapping of the leaves, which are so arranged as to form a beautiful mosaic. These primary functions will be given further consideration in Chapters XIV and XVI.

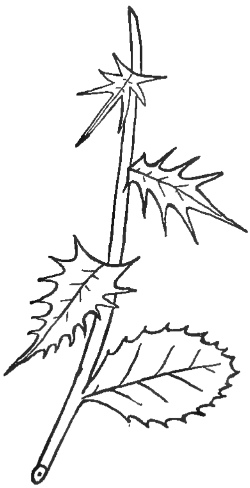
FIG. 55.—Barberry leaves modified into spines.

The secondary functions of the leaves are as follows:

(*a*) *Storage,* in which the leaves are fleshy and usually serve to supply nourishment for flower and fruit stalks, which are produced later. The so-called century plant is a good example of this kind, but the cabbage plant is a much more common example. The cabbage is a biennial which produces its flowers and seeds the second year, using the food that was stored in the leaves during the first season's growth.

(*b*) Leaves serve as *bud scales* for the protection of the true leaves and the flowers within. By carefully removing the scales there will be found a gradual gradation from true scales on the outside to true leaves within (Fig. 20).

(*c*) Leaves are frequently developed as *spines,* in which the veins become firm and sharp, and the mesophyll is greatly reduced. The barberry is an excellent example of this type of leaf (Fig. 55).

(*d*) Leaves are frequently developed for *climbing*, as in the case of the pea and most vetches (Fig. 56).

(*e*) Leaves are sometimes modified into traps for the catch-

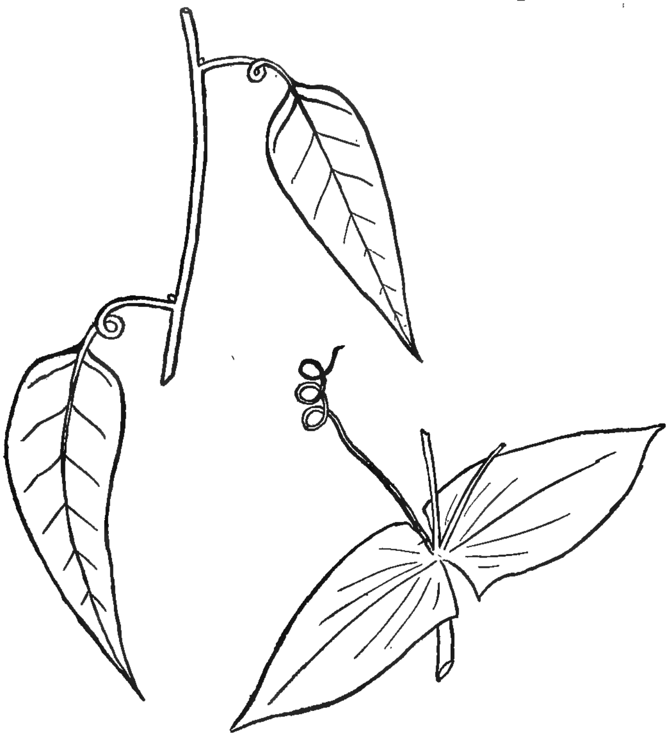

FIG. 56.—Leaves developed for climbing.

ing of insects, as in the case of the pitcher plants, the Venus fly-trap and the sundew (Fig. 57).

Arrangement of Leaves.—The arrangement of the leaves on the stem is also an important characteristic. They may be alternate, opposite, whorled or clustered. They may be arranged on the stem in two, three, five or more ranks. They may be scattered along the stem with long internodes or in a compact mass with short internodes. However, the arrangement is primarily with reference to the air and sunlight, and is such that in most plants there is relatively little overlapping or shading (Fig. 58).

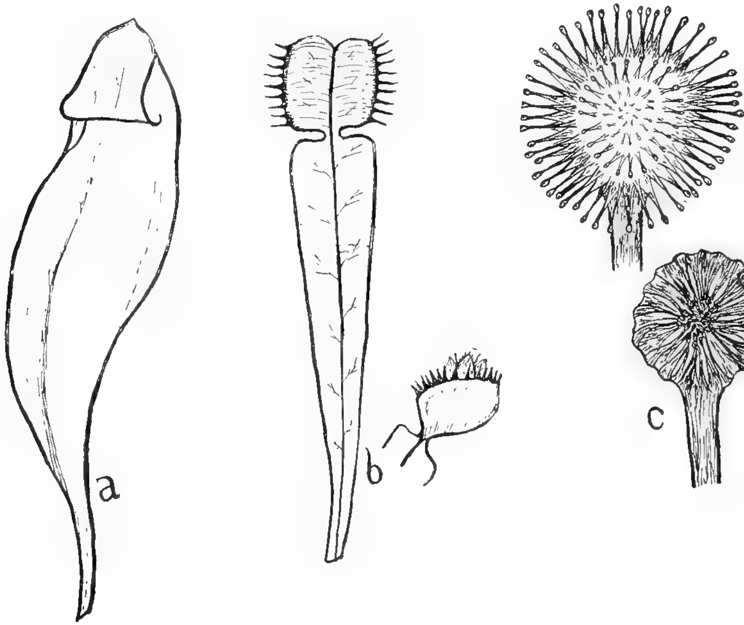

FIG. 57.—Leaves developed for catching insects; (*a*) leaf from pitcher plant, (*b*) leaves from Venus fly-trap, (*c*) leaves from the sundew.

Structure of the Leaf.—The leaf consists of the same tissues as are found in the stem, and they have the same origin. They are arranged so as to form *fibro-vascular bundles, cortex* and *epidermis.* The *fibro-vascular bundles* are a continuation of those found in the stem. They divide and subdivide and form the venation of the leaf. During the process of division the sieve tissues become less and less prominent and are replaced by parenchyma cells and the tracheary tissues are reduced to spirally and reticularly thickened tracheids. They serve to carry water, sugar and other compounds to and from the leaves, as will be explained later (see Chapter XVIII). The primary cortex is represented by the *palisade* and *mesophyll* cells (Fig. 59). The palisade

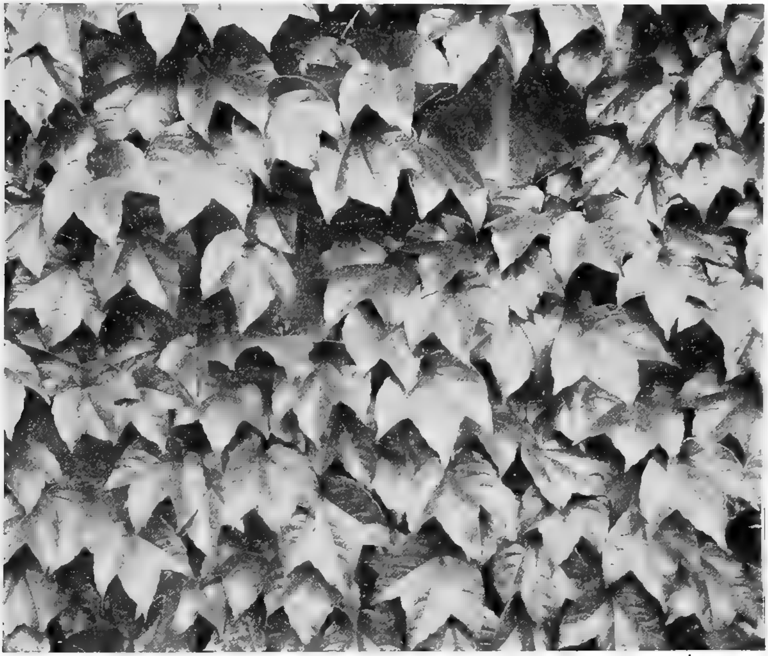

FIG. 58.—Ivy leaves on a wall showing the arrangement with very little overlapping.

cells are more or less cylindrical, very compact and are found just beneath the upper epidermis. They are placed at right angles to the surface. The mesophyll lies between the palisade and the lower epidermis and consists of irregularly shaped cells with numerous intercellular spaces. The palisade and mesophyll cells are parenchyma tissue and are rich in protoplasm.

They also contain the chlorophyll, which is the important factor in the absorption of sunlight and in the making of carbohydrates.

The *epidermis* consists of a layer of cells covering both upper and lower surfaces of the leaf. These cells have lost their protoplasmic contents and the outer wall has become very much thickened and infiltrated with a waxy substance, which makes the leaf water-proof (Figs. 59 and 60). The outer wall is called the *cuticle* and is composed of *cutin,* which is very similar to *suberin*

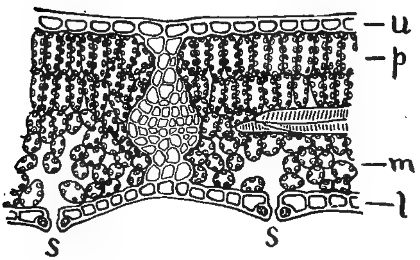

FIG. 59.

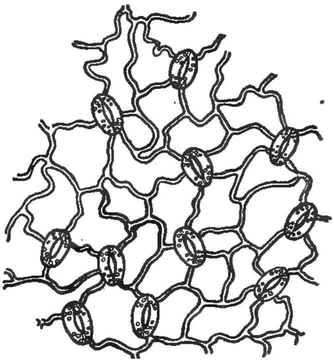

FIG. 60.

FIG. 59.—Cross-section of leaf showing: (*u*) upper epidermis; (*p*) palisade cells; (*m*) mesophyll cells; (*l*) lower epidermis; (*s*) stomata.
FIG. 60.—Lower surface of leaf showing stomata.

(page 52). They protect the more delicate cells within but permit the free transmission of light. On the lower surface we find great numbers of minute openings or stomata (singular, stoma) (Fig. 60). The *stoma* is the opening between two crescent-shaped *guard cells* through which the air passes into a cavity in the mesophyll of the leaf. The *guard cells* are crescent-shaped and differ from the other epidermal cells in being well supplied with protoplasm and chloroplasts. These stomata are usually found in much smaller numbers on the upper surface of the leaf. They open into very irregular and complicated spaces between the mesophyll cells and permit free communication with the air on the outside. These inner cells (mesophyll) take up carbon dioxide, which is used in the making of carbohydrates and give off oxygen and water in the form of vapor. The stomata are also found on green stems and on green fruits but undergo a

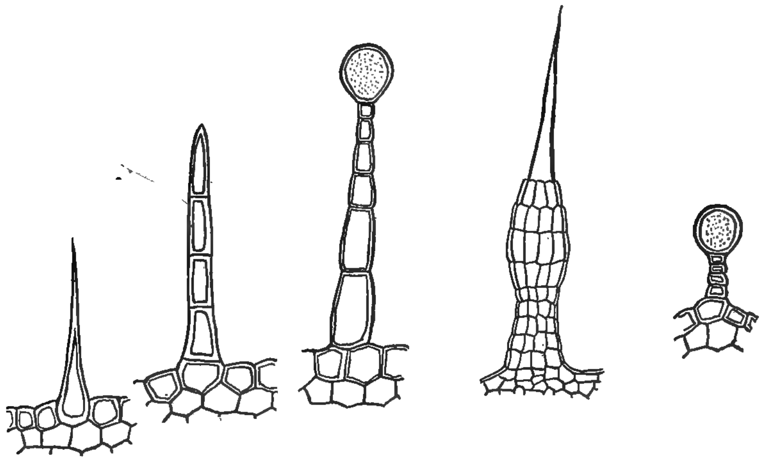

FIG. 61.—Common forms of trichomes.

special development into structures known as lenticels (Figs. 28, 29 and 30) (see page 52). In some plants certain ones of the stomata are modified into structures known as *water pores*. These water pores are enlarged stomata, which are formed at the tips of the veins on the margins of the leaves of the fuchsia, cabbage, nasturtium and many other plants. The water escapes from them in much greater abundance than from the ordinary stomata and frequently collects during the night in very noticeable drops. The passage of water through these pores is known as *guttation* (see page 178). Some leaves are very smooth, while others develop more or less hair-like growths called plant-hairs

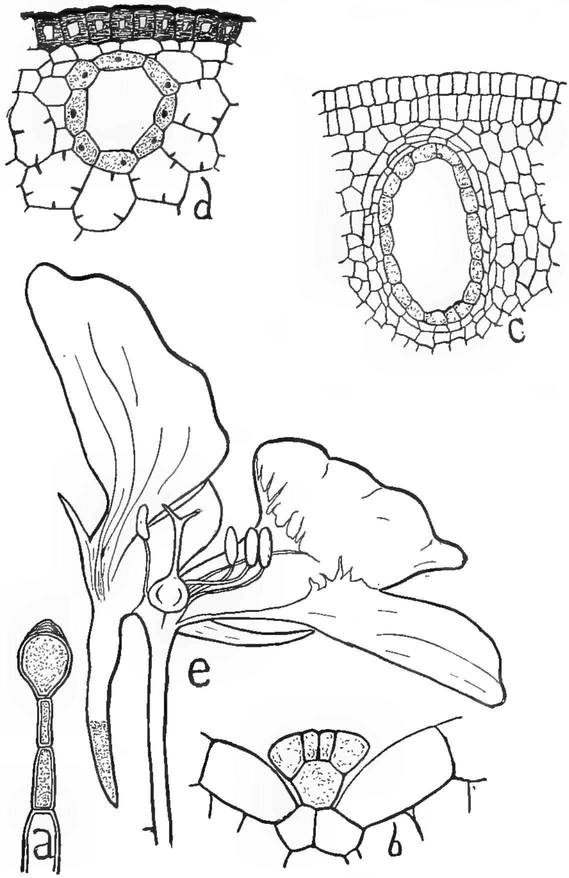

FIG. 62.—(*a*) Gland hair; (*b*) gland on leaf; (*c*) gland in orange peel; (*d*) gland cavity in pine needle; (*e*) flower of nasturtium showing nectar gland spur.

or trichomes (Fig. 61). They correspond to the root-hairs of the roots but present a much greater variety of forms.

Glands.—These are epidermal structures which are extremely variable. The simplest form is a simple trichome in which the apical cell is large and thin-walled. A second type consists of a group of cells in a more or less well-defined pit in the epidermis. Glands of various kinds are found in other parts of the plant (Fig. 62). Some of the most important are the nectar glands in flowers (Fig. 62) and the large glands in the peel of the orange. The glands may secrete water or water containing sugars, enzymes or other products. The sticky character of some leaves and stems and the odor of many plants come from the glands (see Secretions, page 179).

LABORATORY EXERCISES.

Exercise 1. Examine a number of leaves of various plants to determine the parts, forms, types, venation, arrangement and uses so far as possible.

Exercise 2. Examine a cross-section of the leaf. Note the upper epidermis, palisade cells, mesophyll cells, lower epidermis, fibro-vascular bundles, intercellular spaces, stomata, location of chlorophyll and thickening of the outer walls of the epidermal cells.

Exercise 3. Examine the epidermis from both the lower and upper surfaces of leaves of several plants and study the number and arrangement of the stomata and the types of trichomes. Some of the grains should be included in this series.

Exercise 4. Examine the trichomes from the leaves and stems of a number of plants, so as to get some idea as to the great variety.

CHAPTER VI

THE FLOWER

THE **flower** is the most conspicuous part of many plants. The character of the landscape may depend largely on the character of the flowering plants. Many species of plants are grown extensively because of the great beauty of their blossoms. In fact, the flowers are so prominent in many species that many people believe that the study of botany is merely a study of flowers. But the student of botany should remember that the study of the flower is a very small part of the subject. However, the character of the flower is an extremely important factor in the classification of the higher plants and in the study of reproduction.

The size of flowers varies from the almost microscopic forms, such as the duckweeds, to very large and beautiful forms with which we are familiar. However, many of the apparently large flowers, such as the sunflower, are in reality clusters of very small flowers. The *forms* are extremely variable in the different groups and in general are very closely associated with insect visitors. The great variety of *colors* is also closely associated with insect visitors. The *odors* may be pleasant or disagreeable and may also serve for the attraction of insects. The size, form, color and odor of the flower are factors of greatest importance in the selection of plants for ornamental purposes. However, the all-important *function of the flower is reproduction,* a subject which will be taken up in the next chapter.

Parts of the Flower (Fig. 63).—The complete flower consists of a *calyx,* composed of *sepals;* a *corolla,* composed of *petals;* the *stamens* and one or more *pistils* established on a shortened stem known as the *torus* or *receptacle.*

The *calyx* is composed of one or more circles of leaf-like organs, which form the outer covering for the flower bud and the outer part of the open flower. Each part is known as a *sepal.* The sepals are usually green, but in some cases are bright-colored and can be readily mistaken for petals. They may be

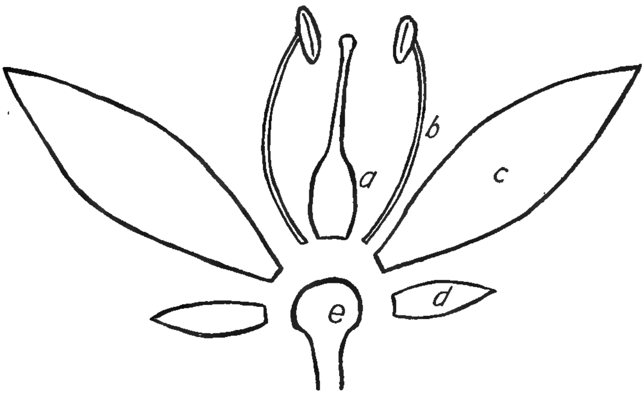

FIG. 63.—The parts of the flower; (*a*) pistil, (*b*) stamen, (*c*) petal, (*d*) sepal, (*e*) receptacle.

separate and distinct or united into a collar-like structure. They are modified leaves which serve primarily for the protection of the other parts of the flower.

The *corolla* is composed of one or more circles of expanded structures just within the circle of sepals. Each part is known as a *petal.* The petals are also specialized leaves and may be leaf-like in form or very much modified. They are usually bright-colored and may be separate or united.

The calyx and corolla constitute the floral *envelope* or *peri-*

anth. Some flowers have neither calyx nor corolla, while others have only the calyx; but most flowers have both.

The stamens (or *microsporophylls*) constitute the one or more circles of organs just within the corolla. Each stamen consists of a stalk-like structure known as the *filament* and a terminal or top part known as an *anther* (or *microsporangium*), which contains *pollen* (or *microspores*). The anther is composed of four, occasionally only two or one, chambers known as *locules.* The stamens may be separate or united, and are attached to the *torus* or to the corolla. Each stamen is a specialized leaf in which the petiole and mid-rib form the filament and the blade the anther. Each pollen grain is a single cell. They are very different in different species of plants.

The *pistil* (or *macrosporophyll*) is the innermost one or more circles of organs. Sometimes several pistils are partly or completely united. Each pistil is composed of a basal part known as the ovary, which contains the *ovules* (or *macrosporangia*), and is surmounted by a slender part known as the *style,* which is in turn surmounted by the stigma. The *stigma* is the only part of the flower without an epidermal covering. The pistil is subject to many modifications, but in all cases it is the central organ of the flower and is composed of one or more modified leaves, which may be partly or completely united. Some flowers have several distinct pistils, which constitute an innermost circle. Each specialized leaf of which the pistil is composed is known as a *carpel.* If composed of only one carpel, it is simple; but if composed of two or more carpels, it is compound.

The carpels of a compound pistil may be united in many ways, but the number of carpels does not necessarily correspond with the number of chambers. Two or three or more carpels attached at their margins may form a pistil of only one chamber, but if the margins are rolled inward, uniting at the center, there will be two or three or more chambers corresponding to the number of carpels. The point of attachment of the ovules is known as the *placenta,* which may be *parietal,* if on the side, or *central,* if in the central axis, or *free central,* if on a free column arising from the center (Fig. 64). The size and number of the

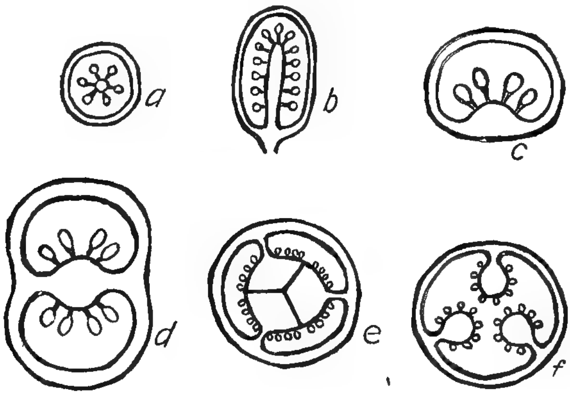

FIG. 64.—Types of ovaries; (*a*) and (*b*) one carpel, one chamber, central placenta; (*c*) one carpel, one chamber, parietal placentæ; (*d*) two carpels, two chambers, central placenta; (*e*) three carpels, three chambers, central placenta; (*f*) one chamber, three carpels, parietal placenta.

ovules vary greatly in different species of plants. The parts of the ovule will be taken up in the next chapter.

The stamens and pistils constitute the *essential organs* of the plant. They are, in a sense, the reproductive organs of the plant and are necessary for seed production. A flower to be functional must possess one or the other or both of these organs. The processes of reproduction will be discussed in the next chapter.*

* The significance of the terms *microsporophyll, macrosporophyll, microsporangium, macrosporangium,* and *microspore* will be explained in Chapters XXVI–XXVIII.

Modifications of the Flower

The flower is subject to innumerable modifications: such as (1) the absence of parts, (2) the variation in number of parts, (3) the union of parts and (4) the modification in form of parts. A *complete* flower is one that contains all four sets of organs, such as the apple or peach blossom. If any set of organs is missing, as the corolla in the anemone or wind-flower, it is

FIG. 65.

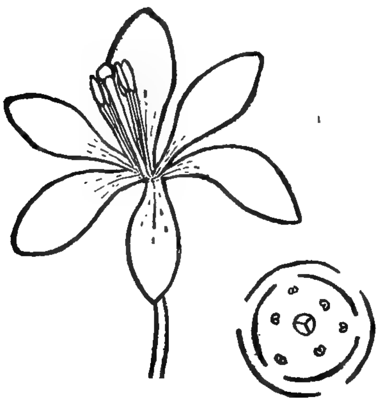

FIG. 65.—Diagrammatic cross-section of lily. Regular flower.

FIG. 66.

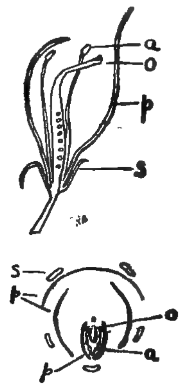

FIG. 66.—Diagrammatic longitudinal and cross-section of pea blossom. Irregular flower.

incomplete. Flowers without corollas are very generally grouped as *apetalous,* and if both corolla and calyx are missing they are *naked.* If all the parts of each circle are alike in shape and size, as in the apple and peach, it is *regular* (Fig. 65), but if unlike, as in the violet or pea, it is *irregular* (Figs. 66 and 67). If there are an equal number of parts on each circle, as in the lily, it is *symmetrical,* but if unequal, as in the wild roses, which have numerous stamens, it is *unsymmetrical.* If both stamens and pistils are present, it is perfect (*hermaphroditic*), regardless of the presence or absence of the calyx and corolla. If either stamens or pistils are absent, it is imperfect (*diclinous*). If the stamens only are present, it is *staminate.* If the pistils only are present, it is *pistillate.*

When both the staminate and pistillate flowers are on the same plants, as in the corn and castor-oil plants, it is *monœcious* (one household), but if on different plants, as in the willows and

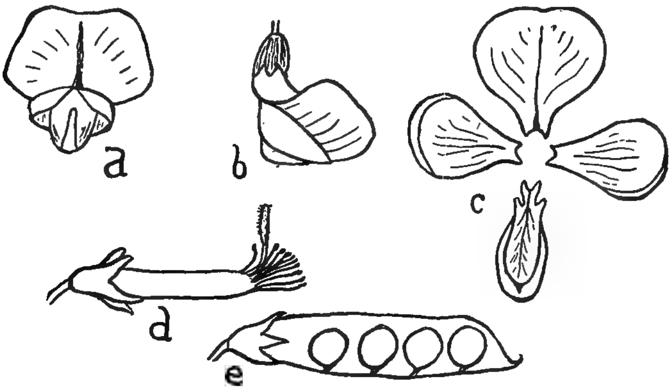

FIG. 67.—Legume blossom; (*a*) and (*b*) the blossom; (*c*) the blossom dissected showing the petals; (*d*) the sepal, stamen and pistil; (*e*) the mature seed pod.

mulberries, it is *diœcious* (two households). When some of the flowers on an individual plant are perfect and others imperfect it is *polygamous.*

If the parts of the flower are attached below the ovary, the ovary is *superior;* but if above, it is *inferior.* If each set or circle of organs is free from the other circles, the flower is *hypogynous;* if the sepals, petals and stamen arise from an urn-like structure surrounding and inserted below the pistil, the flower is *perigynous.* If the urn is closed so that all the organs appear to arise from the top of the ovary, the flower is *epigynous.*

If the sepals are independent of each other, it is *polysepalous;* but if the edges are united, it is *gamosepalous.* If the petals are independent of each other, it is *polypetalous;* but if the edges are united, it is *gamopetalous.* If the stamens are united into one

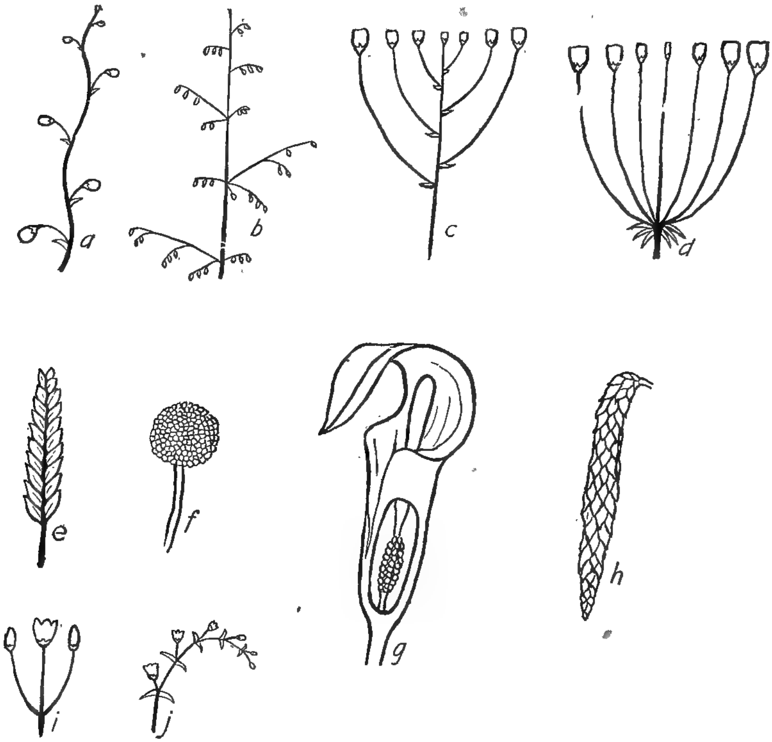

FIG. 68.—Types of inflorescence; (*a*) raceme, (*b*) panicle, (*c*) corymb, (*d*) umbel, (*e*) spike, (*f*) bead, (*g*) spadix, (*h*) catkin, (*i*) cyme, (*j*) scorpioid cyme.

group, it is *monadelphous* (one brotherhood); but if united into two groups, it is *diadelphous* (two brotherhoods).

Specialization of the Flower.—We have previously called attention to the fact that the flower is a shortened stem surmounted by specialized leaves which constitute its various parts.

The leaf-like character of the ordinary sepal is very generally recognized. The petals are rarely green, but otherwise there is no good reason for believing that their origin is materially different from the sepals. In many flowers the petals are of some color other than green, and in many cases it is difficult to distinguish the calyx from the corolla. The stamens and pistils appear to be very different from the leaves, but it is nothing uncommon to find specimens in which these organs are petal- or leaf-like. In fact, the white water lily shows a gradual transition from stamens to petals and from petals to sepals. Many of our so-called *double flowers,* such as the roses and carnations, are cases in which the stamens have reverted into petals.

Inflorescence (Fig. 68).—The arrangement of the flowers on the stem is called the *inflorescence.* It may be expressed in diagram as follows:

- Inflorescence
  - Solitary
    - Axillary
    - Terminal
  - Clustered
    - Corymbose (Indeterminate)
      - Raceme
      - Panicle
      - Thyrsus
      - Corymb
      - Umbel
        - (Corymb, Umbel:) Simple
        - (Corymb, Umbel:) Compound
      - Spike
      - Head
      - Spadix
      - Catkin
    - Cymose (Determinate)
      - Cyme
      - Helicoid cyme
      - Scorpioid cyme

Solitary, of course, refers to lone flowers, as compared with *clustered* or grouped flowers. The former are borne on short shoots in the axils of the ordinary leaves (*i.e., axillary*), or at the tips of the main shoots (*i.e., terminal*).

In the clustered inflorescence the flowers are grouped on an axis which may be long or short. In the *corymbose* or *indeter-*

minate group the buds begin to bloom at the base of the axis, while in the *cymose* or *determinate* group the buds at the tip of the axis are the first to bloom.

In the *raceme* the flowers are arranged along an elongated axis, and there is a small leaf-like structure or bract at the base of each flower. Common examples are the lily of the valley, the wild cherry and the currant. Sometimes the racemes are branched and therefore known as *compound racemes,* as in the case of the false Solomon's seal.

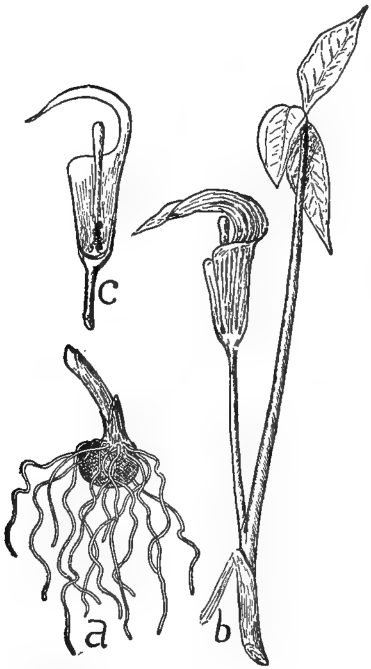

FIG. 69.—Indian turnip or Jack-in-the-pulpit; (*a*) bulb; (*b*) leaf and spathe; (*c*) spathe open to show spadix and flower near the base.

The *panicle* is a loose, compound, somewhat irregular raceme, such as is found in the oat and some of the grasses.

The *thyrsus* is a compact pyramidal panicle, such as is found in the lilac and the horse chestnut.

The *corymb* is a raceme with a somewhat shortened axis and in which the peduncles (*i.e.*, stem for each flower) of the lower flowers are elongated so as to bring all the flowers on about the same level, as in the case of the mountain ash.

The *umbel* has such a very short axis that the peduncles appear to arise from the same point, as in the case of the milkweed and the wild carrot. We also find the compound type of umbel.

The *spike* has a very long axis, the flowers are sessile (*i.e.,* without pedicles) and usually crowded, as in the plantain, mullein and wheat.

The *head* has a very short axis, the flowers are sessile and so crowded as to form a dense cluster, as in the case of the dandelion, sunflower, button bush and plane tree.

The *spadix* is a very fleshy spike, such as is found in the Indian turnip and calla. It is usually more or less enclosed by an enlarged sheathing bract, or leaf-like structure known as the *spathe* (Fig. 69).

The *catkin* or *ament,* a scaly spike bearing either staminate or pistillate flowers. They are usually pendent and are characteristic of the willows, poplars, oaks and many other trees. The staminate catkins are more common than the pistillate.

The *cyme* is similar to the raceme except that the order of blooming is the reverse. In most cases the lower peduncles are longer than the upper, which brings all of the flowers on very nearly the same level. In the *scorpioid type* the branches are alternate, while in the *helicoid* type the branches arise from one side and thus give rise to a curved flower axis.

The types of flowers and inflorescence are illustrated in Part III. They may be studied at this time or at such later period in the course as may be most convenient.

LABORATORY EXERCISES.

Exercise 1. Use any complete flower in which all the parts are easily recognized. Note the relation, size and shape of the sepals and petals, and the arrangement of all the parts.

Note the parts of the stamens and pistils.

Examine the pollen under the microscope.

Examine cross and longitudinal sections of the ovary. Determine the number of carpels and union. How are the ovules attached? Estimate the number of ovules.

Exercise 2. Different types of flowers can be studied at such time as may be most satisfactory.

Exercise 3. Examine the pollen grains of several flowers, using the compound microscope.

CHAPTER VII

PLANT REPRODUCTION

All living things tend to reproduce their kind. If they did not do so, they would pass out of existence and their race would become extinct. All species of plants and animals are engaged in a continuous struggle for existence (Chapter XXI). Many species have ceased to exist, and we know of them only by their fossil remains, which we find in and on the crust of the earth. The most prominent and important organs in the reproduction of most of the higher plants are the flowers, although many plants reproduce by means of other structures. *The flower is a specialized shoot, and the parts are specialized leaves, and its primary function is reproduction.* The shoot is very short, and the parts are brought very close together.

Reproduction.—There are two methods of reproduction: the sexual and the non-sexual. In the higher plants sexual reproduction involves the two sets of sexual organs, stamens and pistils, which may be borne on the same or on different plants, while in the non-sexual or vegetative method the sexual organs are not involved and there is but one parent.

Sexual Reproduction.—In our higher plants this involves the transfer of the pollen from the stamen to the stigma of the pistil of another (occasionally the same) flower, the formation of a pollen tube which grows through the length of the style and penetrates the ovule. A male nucleus (*gamete*) from the pollen tube enters the ovule and unites with a female nucleus (*gamete*) and gives rise to an embryo or new plant enclosed within a seed. Therefore it will be readily seen that the embryo is formed within and is the essential part of the seed.

Pollination.—The transfer of the pollen from the stamen to the stigma of the pistil is called *pollination.* If the pollen is transferred to the stigma of the same flower, it is *self-pollination;* if to the stigma of another flower on the same plant, it is *close pollination;* and if to the stigma of a flower on another plant, it is *cross-pollination.* In some flowers self-pollination is absolutely necessary, because the flower buds never open, while in others it is impossible, because the staminate and pistillate flowers are on different plants. However, the study of a large number of plants indicates that self-pollination is rare and that close and cross-pollination are very general.

Methods of Pollination.—There are several methods of pollination in the plant kingdom. They are the (1) *cleistogamous,* in which the bud never opens, as in the case of some violets; therefore, self-pollination; (2) *anemophilous,* in which the pollen is carried by insects, as in the case of most flowering plants. The insects are probably attracted to the nectar, which is secreted by special glands, or by the odor or possibly by the bright colors. The peculiar forms of the corolla are frequently associated with some particular species of insects. In some species this is so pronounced that the plant is dependent on a single species of insects for pollination and cannot produce seeds unless this particular species of insect is present. In addition to these methods, birds are sometimes carriers of pollen, and in some very few cases the pollen is carried by water. However, the fact that many plants live in the water does not indicate that the pollen is carried by water; in most water plants the flower is held above the water and the pollen carried by the wind or by insects.

It is very evident that the anemophilous and entomophilous methods will usually result in either close or cross-pollination. In fact, nature appears to have provided against self-pollination in the great majority of plants. In some plants the stamens and pistils mature at different times and the pollen must be carried to the stigma of another plant in order to be functional. Other plants have various devices which result in their insect visitors carrying the pollen to other flowers, but prevents its being deposited on the stigma of the same flower.

It will be readily seen that much of the pollen must be lost and wasted. Only a comparatively few pollen grains ever reach the stigma of a flower of the same species and grow. However, there must be one active pollen grain for every ovule that is fertilized. Therefore, when we take into consideration the great waste and the great number of seeds that are produced by some plants, it will be readily seen that the number of pollen grains produced must be enormous. An ordinary corn plant produces about 50,000,000 pollen grains, or an average of 7000 for each grain that is produced. Therefore, about one pollen grain in every 7000 serves its function.

Fertilization.—The term *fertilization* is used in this connection to indicate the union of the male nucleus which is produced by the pollen grain with the female nucleus which is produced by the ovule. Unfortunately, the same word is used to indicate the enrichment of the soil by the application of manures and chemicals.

The *pollen grain* (or *microspore*) is originally a single cell (Fig. 70). The nucleus divides into a *tube nucleus* and *genera-*

tive nucleus. This usually occurs just before or at the time of the transfer of the pollen grain to the stigma. The *generative* nucleus divides into two *sperm* or *male nuclei.* The pollen grain produces a tube which penetrates the stigma and grows down the style. The tube nucleus enters the tube followed by the two sperm nuclei. Their further history will be followed later (see pages 97 and 98).

The position of the ovules with reference to their form and

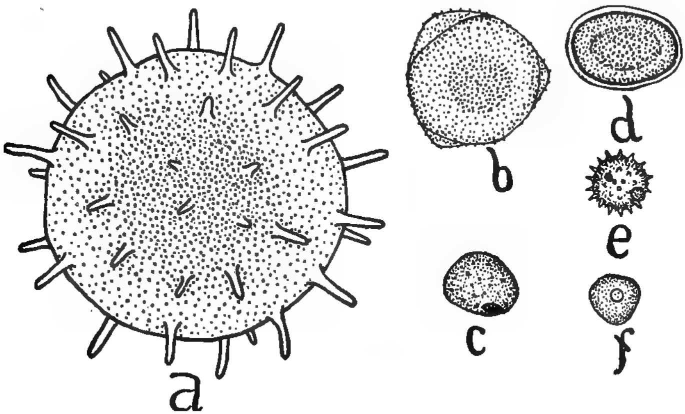

FIG. 70.—Types of pollen grain.

attachments enables us to classify them as follows: (*a*) The *orthotropous* or *straight* ovule, of which the common buckwheat is an example—the chalaza is at the base and the micropyle at the opposite end. (*b*) The *campylotropous* or *incurved* ovule, of which the common chickweed is an example—the ovule is curved and somewhat crescent-shaped. (*c*) The *amphitropous* or *half-inverted* ovule, of which the mallow is an example—the ovule is not curved, but at right angles to the stem, which extends half the length of the ovule to the chalaza. (*d*) The *anatropous* or *inverted ovule,* of which the violet is an example—the ovule is inverted and the stem or funicle extends the full length, as the raphe (Fig. 71).

The ovules (Fig. 72), which are borne within the ovary, are

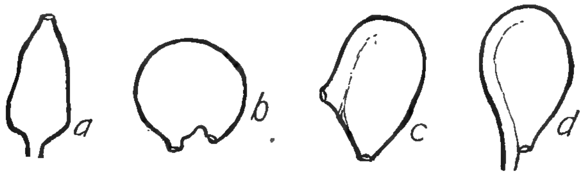

FIG. 71.—Types of ovules; (*a*) orthrotropous, (*b*) campylotropous, (*c*) amphitropous, (*d*) anatropous.

to develop into the seeds. Each mature ovule is composed of a mass of cells, which is known as the *nucellus,* and is surrounded by one or usually two *integuments,* which are to become the *seed coats* (Fig. 73). The *micopyle* is a very small opening in the integuments through which the pollen tube penetrates to the nucellus. The other parts of the ovule are the *chalaza,* or point of union between the nucellus and integuments; the *hilum,* or point where the ovule is attached to the ovary wall by means of a short stem-like structure known as the *funicle* or *funiculus;* and the *raphe,* which is the extension of the funiculus along the side of the ovule.

FIG. 72.—Diagrammatic longitudinal section of ovary showing developing ovules.

An *embryo sac,** consisting of eight nuclei, is formed in the nucellus near the micropyle (Figs. 73 and 74). In the mature embryo sac the eight nuclei are so grouped that there are three at each end of the sac and two in the central part. The three nuclei at the micropylar end of the embryo sac constitute the egg

* The formation of this embryo sac will be explained in Chapter XXVIII.

apparatus; one is very large and known as the egg or female gamete, while the other two are known as the synergids. The three nuclei at the opposite end of the embryo sac are known as

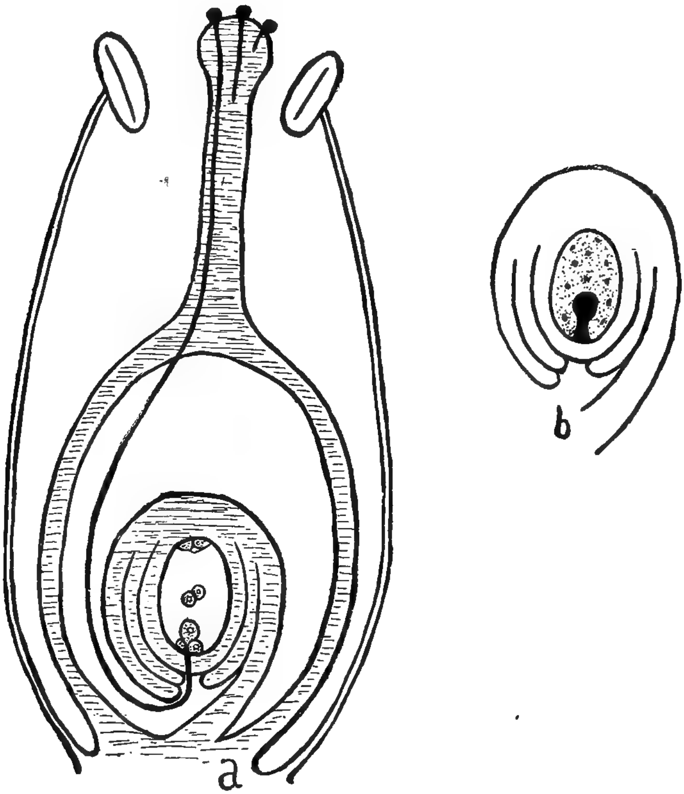

Fig. 73.—(a) Diagrammatic drawing of stamens and pistil showing longitudinal section of ovule. The pollen tube is entering the micropyle; (b) longitudinal diagrammatic section of ovule showing the formation of the embryo and endosperm.

the *antipodals.* The two nuclei in the central part of the sac are known as the *polars.*

The pollen tube, to which we have previously referred, having grown down through the style, enters the ovary, then through the micropyle and into the nucellus and eventually into the synergid end of the embryo sac. The two sperm nuclei are discharged into the embryo sac and one, which may be called the male gamete, unites with the egg or female gamete. This union of the two sex nuclei is the true *fertilization* and gives rise to the *embryo plant* within the mature seed. The two polar nuclei unite and form the *endosperm nucleus,* which gives rise to the *endosperm* of the seed. In many cases, possibly in all, the second sperm nucleus unites with the endosperm nucleus; when this occurs it is known as *double fertilization.* The antipodal nuclei usually disintegrate, but in some cases appear to be important factors in the nourishment of the embryo.

The Formation of the Seed.—The further development includes a number of structures:

(1) The *embryo* is at first a single cell formed by the union of two nuclei, the sperm and the egg. This cell undergoes repeated divisions, the resulting cells undergoing more or less differentiation to form the first organs of the embryo or young plant. These organs include the cotyledons, the *plumule,* the *radicle* and the *hypocotyl,* which are described in Chapter IX.

(2) The *endosperm* (Fig. 74, *d, e, l*) arises from the divisions of the *endosperm* nucleus and together with the embryo, more or less completely fills the embryo sac. It is very rich in stored foods and is the first nutriment used by the embryo when the seed germinates.

(3) The *perisperm* of the mature seed is developed from the nucellus. It is well supplied with food, which is used by the embryo during the period of germination.

(4) The *seed coats* (Fig. 73) of the mature seed are the

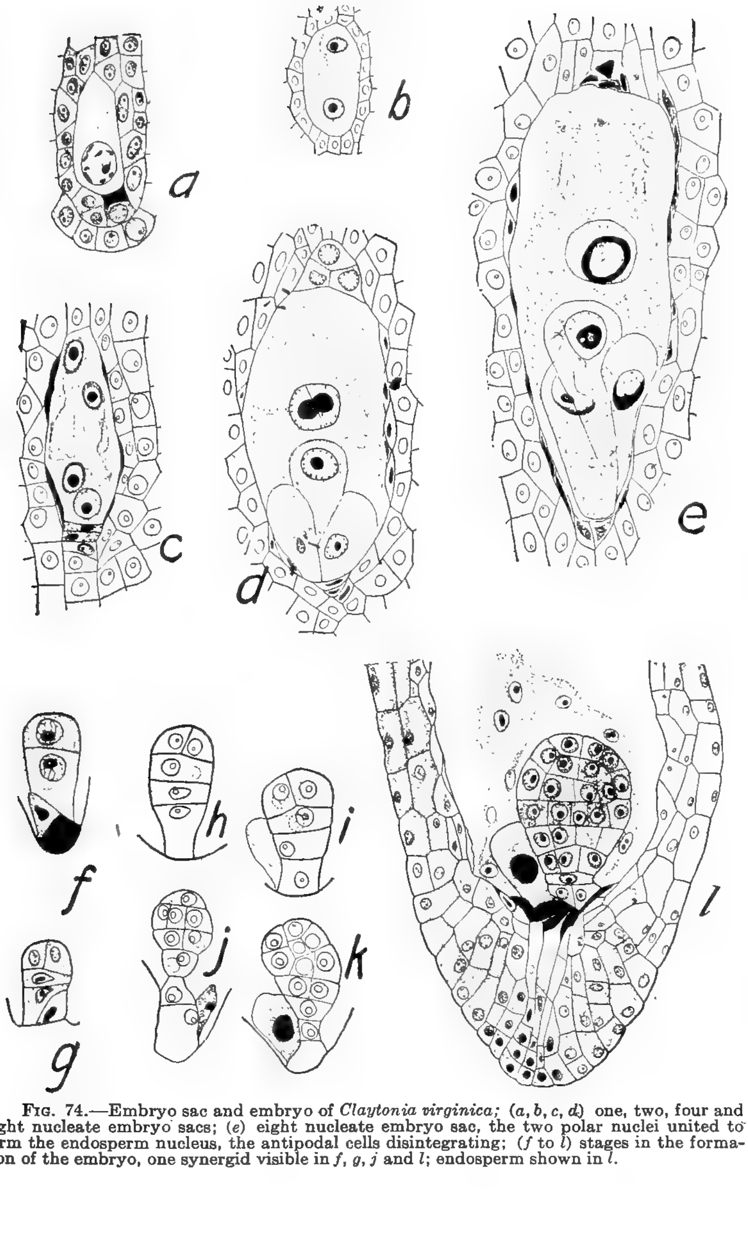

FIG. 74.—Embryo sac and embryo of *Claytonia virginica;* (*a*, *b*, *c*, *d*) one, two, four and eight nucleate embryo sacs; (*e*) eight nucleate embryo sac, the two polar nuclei united to form the endosperm nucleus, the antipodal cells disintegrating; (*f* to *l*) stages in the formation of the embryo, one synergid visible in *f*, *g*, *j* and *l*; endosperm shown in *l*.

modified integuments of the ovule and form a protective covering for the embryo, endosperm and perisperm.

Mature seeds from different species of plants show considerable variation in size and form, in size of the embryo, and in the relative amounts of endosperm and perisperm. In some seeds the perisperm is very abundant and is the most important source of reserve food. In others the embryo grows very rapidly, gradually absorbing the endosperm. Therefore, we find seeds (1) with embryo, endosperm, perisperm and seed coats, as in the seeds of the pepper and water lily; (2) with embryo, endosperm and seed coats, as in the seeds of the castor-oil plant and Jamestown weed; or (3) with embryo and seed coats, as in the bean and pea. These different types of seeds will receive further consideration in Chapter IX.

The various stages in the formation of the embryo sac and embryo must be studied with the microscope in order to get a thorough understanding of them. They are illustrated in Fig. 74.

Secondary Effects of Pollination and Fertilization.—Although the primary function of pollination and fertilization is the formation of a seed containing an embryo from which a new plant will be produced, there are several secondary physiological effects. The first is the production of fruits; many plants, such as melons, cucumbers and fruit trees, will not produce normal fruits unless fertilization has occurred. Partly developed cucumbers and one-sided apples usually result when only a part of the ovules have been fertilized. Many of the plants will not set fruit unless fertilization has occurred. Other plants, such as the banana and the seedless orange, will produce excellent fruits without fertilization; they are known as *parthenocarpic* fruits. Some fruit trees will set very little or no fruit unless they have been pollinated with pollen from other varieties. This becomes an important factor in the setting of orchard trees and determines whether the grower can set an orchard of a single variety or must use a mixture of varieties in order to secure a crop of fruit. A second function is the effect on the endosperm, which is very evident in corn and is known as *xenia.* In this case the effect of the second male sperm on the endosperm can be seen through the seed coats. It is well illustrated where two varieties of corn are grown together; some of the ovules having been pollinated with pollen from plants of the same variety and others with pollen from plants of a different variety, results in ears with two types of grains. In most species of plants this xenia character is lost in the seeds and fruits, due to the absorption of the endosperm by the embryo, or to concealment by the coverings.

Parthenogenesis and Polyembryony.—Some plants, such as the dandelion, will produce seeds without fertilization; this process is known as *parthenogenesis.* Seeds occasionally produce more than one embryo; this may be due to the formation and fertilization of more than one ovum or to the formation of embryos from nucellar tissue within the embryo sac or both. The seeds of the orange frequently produce several embryos, one of which may be from a fertilized egg, while the others are from the nucellus. This becomes an important factor in the cross-breeding of related plants for the development of new varieties, since the embryo from the fertilized egg is the only one that will possess character of both parents, the others possessing characters of the mother plant only.

Non-Sexual Reproduction.—Most of the higher plants can produce new individuals without the intervention of sexual organs and some of them reproduce entirely or almost entirely in this way. By this method new plants may be produced from stems, bulbs, roots and occasionally from leaves.

It is well known that many plants, such as lilies, tulips, hyacinths and onions reproduce by means of bulbs, which are modified stems (Fig. 19). Some of these bulb-producing plants also reproduce by means of seeds, but others depend entirely on the bulbs. The growing of bulbs, especially of ornamental plants, is one of the very important industries.

Some plants, such as the strawberries, reproduce by runners (Fig. 15) or modified stems which grow along the surface of the ground, take root and produce new plants, while others, such as the mints, the couch or quick-grass and many others, reproduce by rootstocks or rhizomes, which grow just beneath the soil (Fig. 17). Other plants, such as the potato, reproduce by means of tubers (Fig. 18), which are fleshy underground stems. They are propagated for agricultural purposes by cutting the tuber in pieces. It is very difficult to destroy the rhizome type of plants, because cultivation merely breaks these underground stems in pieces and each fragment carrying a bud produces a new plant; therefore, the number of plants is materially increased. Many other plants, such as blackberries and raspberries, reproduce by means of "suckers" or new plants which grow directly from the lower part of the old stem. The stems of many plants, especially the shrubs, will take root and grow if they come in contact with the soil or become partly covered with soil. Many trees and shrubs, especially the willows and poplars, self-prune; *i.e.,* drop the branches, during the growing season (Fig. 75). These self-pruned shoots frequently become partly covered with soil and grow. Some few plants, such as the *Bryophyllum*, produce buds and new plants from the margins of the leaves, but this method is comparatively rare.

Many of the principles of plant propagation as practiced by the horticulturists are based on the above facts concerning plant

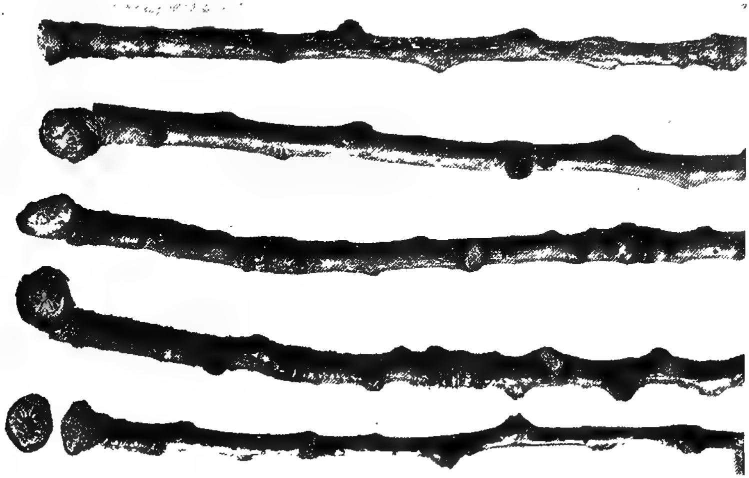

Fig. 75.—Self-pruned twigs of the poplar showing the cleavage planes.

growth. Many herbaceous plants, such as geraniums, begonias and carnations, are grown almost entirely from cuttings.

Grafting.—This is an art which is very generally practiced by the horticulturists in the growing of fruit trees and many other plants. It consists in uniting the parts of two growing plants, known as the *stock* and the *scion*, in such a manner that the tissues will unite into a single plant. The *stock* is the root, or root and part of the stem, and should be a strong, vigorous plant; the *scion* is a twig or bud from a plant which it is desired to perpetuate and therefore produces desirable flowers or fruit.

The stock and scion must be closely related and must be so placed as to bring the growing tissues of the two in contact. If the work is properly done, the tissues of the two will unite, the wound heals and a desirable plant is produced. Grafting is of two types: the *cleft* and *whip*. In cleft grafting a branch of the stock is cut off and split and one or two wedge-shaped scions, with buds, inserted (Fig. 76). The wound is then covered with grafting wax. In whip grafting, which is the method usually

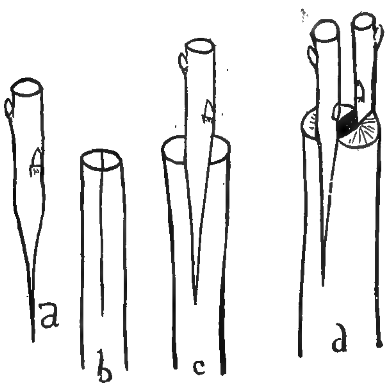

FIG. 76.—Steps in cleft grafting; (*a*) the scion, (*b*) the stock, (*c* and *d*) the scion and stock united.

FIG. 77.—Steps in whip or tongue grafting; (*a* and *b*) root and scion properly cut, (*c*) the two parts in position. (Productive Farming.)

practiced with seedlings, both stock and scion are cut obliquely, split, united (Fig. 77) and wrapped. Grafting is most commonly practiced in the spring of the year.

Budding is also an art in plant production and is practiced for the same purpose as grafting (Fig. 78). In budding a T-shaped incision is made in the bark of the stock plants, and a bud (*i.e.*, scion) with wood and bark attached is taken from a tree of the desired variety. The bud is inserted in the slit in the stock and wrapped so as to hold it firmly in place. The two cambiums unite, the scion grows and finally the stock is pruned, so that the shoot from the scion is the only one remaining. Budding is usually practiced in the fall.

Both grafting and budding are of the very greatest importance in the maintaining and growing of plants in which the seeds do not produce plants exactly like the parent. Many of our fruits, and especially many woody plants, such as grapes,

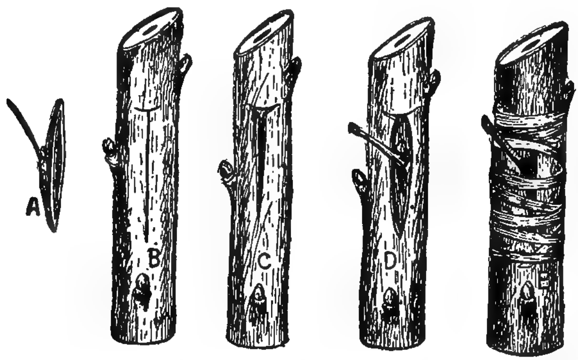

FIG. 78.—Steps in budding; (*a*) the bud or scion, (*b*) the T-shaped slit in the bark of the stock tree, (*c*) same opened, (*d*) the bud in place, (*e*) the wound wrapped with raffia or waxed cotton. (Productive Farming.)

roses, privet, willows and poplars, are propagated by means of stem cuttings.

Results of Non-Sexual Reproduction.—Many plants in which the non-sexual methods of reproduction are highly developed have partially or completely lost the power of producing seeds. The potato and many of our bulb plants are never grown for seed, except for experimental purposes. Bananas, pineapples and a great number of ornamental plants are grown entirely from cuttings. Many plants do not come true from seeds; *i.e.*, the offsprings are very different from the parent. Therefore, the only way they can be propagated with any assurance of securing the desired result is by means of some one of the non-sexual methods. The apples and peaches do not "come true to seed"; that is, the new plants grown from the seeds produce fruits quite different from the parents. Therefore, in order to perpetuate a desirable fruit, it is necessary to graft or bud scions of the desirable plant onto strong stocks.

In the great majority of cases the new plants are produced from stems, but in some cases new plants are produced from roots. The sweet potato is a good illustration of a plant in which the stems are produced from roots. In the growing of this very important crop the roots are layered in especially prepared beds, and produce great numbers of plants, which are pulled and set in the field. Many trees, such as the plums and poplars, produce shoots or sprouts from the roots.

Variations.—It is said that nature produces no two individuals that are exactly alike; sometimes the variations are so slight as to be almost imperceptible, while in other cases they are very pronounced. These variations may occur in any part of the plant; they may involve size, form, color, chemical composition or any other character of the plant. Therefore, new types are constantly arising in every generation. Most of them are very unstable, and therefore disappear in the next generation. This is especially true of many of our fruits, such as the apple and the peach, which are extremely variable. Fortunately the valuable varieties of orchard fruits that arise in this manner can be perpetuated by budding and grafting.

Mutations.—Sometimes variations are produced which come quite true from the seed; they are known as *mutants*. Many horticultural varieties of fruits, vegetables and grains have originated in this manner. Bud mutants are also occasionally produced.

Plant Breeding.—This is a branch of botany which has been developed in recent years and has for its object the production of new and valuable plants. It involves not only the selection of valuable variations and mutations, but also the hybridization of plants. In fact, *hybridization* may be considered the most important part of the work. It consists in the cross-pollination of related plants and in the study of the resulting offsprings. It is a very complicated subject and requires a special training to insure success.

LABORATORY EXERCISES.

Exercise 1. Examine germinating pollen grains.

Method: Fasten a glass ring to a slide with balsam; sterilize the slide, ring and a cover glass. Boil a 10 per cent. sugar solution for a few minutes; put a drop on the cover glass by means of a sterilized wire; inoculate with pollen, invert over the ring and examine in a few hours.

Exercise 2. Examine prepared slides of ovules showing the one, two, four and eight celled stages of the embryo sac.

Exercise 3. Examine prepared slides showing different stages of embryo growth. Also note the endosperm, nucellus and integuments.

CHAPTER VIII

FRUITS AND SEEDS

The Fruit.—This term is strictly applied to the ripened ovary and its contents or in some cases to the ovary and its contents plus the other parts of the flower that have united with it. The character of the fruit depends on the various combinations of ovaries and other parts, number of ovaries and seeds and texture of ovary walls. Therefore, we have many types of fruits, some of which may be very similar in general appearance but very different technically. Fruits may be divided into two groups,

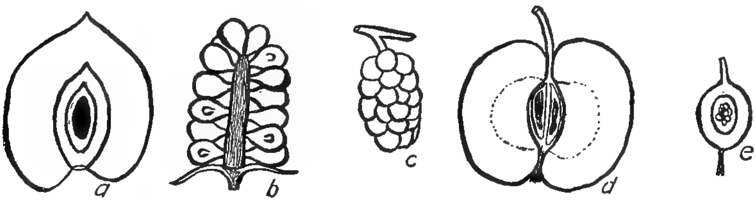

FIG. 79.—Types of fleshy fruits; (*a*) drupe, (*b*) collective drupe, (*c*) multiple drupe, (*d*) pome, (*e*) berry.

which are described by their names, fleshy fruits and dry fruits. The wall of the ovary of many of the fleshy fruits may be divided into three parts: (1) the *exocarp* or outside layer, which is usually an epidermal covering; (2) the *mesocarp* or middle layer, which is composed of parenchyma tissue, is usually very thick and sometimes very juicy; and (3) the *endocarp* or inside layer, which may be stony, as in the peach, or papery, as in the apple (Fig. 79).

Some authors use only two terms: the *exocarp,* for both the outside covering and the fleshy parts, and the *endocarp,* for the inside stony part or core. Owing to the great variation in the character of fruits on different species of plants, it is very difficult to make a scientific classification. But for the convenience of study they can be classified as follows:

- **Fruit**
  - Fleshy
    - Drupe (Stone fruits)
      - Simple
      - Aggregate
      - Multiple
    - Accessory
    - Pome
    - Berry
  - Dry
    - Dehiscent
      - Pod or Capsule
      - Follicle
      - Legume
      - Silique
      - Pyxidium or Pyxis
    - Indehiscent
      - Achene or Akene
      - Caryopsis
      - Samara or Key
      - Nut

The simple *drupe or stone fruit* has the seed surrounded by a hard stony structure (endocarp), which is in turn surrounded by the fleshy part (mesocarp), which is in turn surrounded by the epidermal covering (exocarp). The peach, plum and cherry are typical examples of *simple drupes* (Fig. 79, *a*). Each fruit is derived from a single or simple ovary of an individual flower. The other types of drupes are modifications of the simple drupe, and the differences are superficial rather than real. They are: (*a*) *the aggregate drupaceous fruit,* which consists of a number of ripened fleshy ovaries, all of which are derived from a single flower. These individual, mature ovaries are usually clustered on a torus, but are not otherwise different from the simple drupe. The blackberry and raspberry are good illustrations of this fruit (Fig. 79, *b*). (*b*) *The multiple fruit* also consists of a number of mature, small and compact ovaries, but each ovary is derived from a single flower (Fig. 79, *c*). This type of fruit is well illustrated by the mulberry.

These individual flowers and the mature ovaries derived from them are usually small and are clustered on a common rachis. The mulberry and pineapple are types. It will be readily seen that although the blackberry and mulberry show a striking superficial resemblance they are very different, the former being derived from a single flower with many pistils or carpels and the latter from the pistils of a number of small individual flowers. The term "berry" as applied to these fruits is unfortunate; botanically they are not true berries, but the name is so closely associated with them that we must continue to use it.

The *accessory fruit* is quite different from any of the other fruits. It is a combination of the fleshy and dry fruits and is illustrated by the strawberry (Fig. 191). The edible part is the enlarged fleshy torus or receptacle on the surface of which are numerous *achenes,* which are usually but incorrectly called seeds. (See achene, page 111.)

The *pome* is a fruit in which the ovary or ovaries and the calyx have united and become fleshy. The base of the calyx extends over the ovary and the tips of the sepals persist at the blossom end of the fruit. The *endocarp* is developed as a papery case. The apple, pear and quince are types of this fruit (Fig. 79, *d*).

The *true berry* consists of a more or less leathery structure, enclosing a mass of seeds (Fig. 79, *e*). It may consist of an ovary only, or of an ovary enclosed in the calyx. A great many plants belonging to a great diversity of families bear fruits of the true berry type, although radically different in size and appearance. Some of the most important are the gooseberry (Fig. 183), currant, huckleberry, cranberry, grape, orange, melon, gourd, cucumber. The last three belong to the family *Cucurbitaceæ* and from their large size, inferior ovary and thick skin are usually referred to by the special name of "*pepo.*"

The *dry fruits* are those in which the fruit is a dry structure, usually known as a pod. If this pod opens and releases the seed, it is *dehiscent,* but if it does not open until forced open by the germinating seed, it is *indehiscent.* The term *pod,* or *capsule,* is used to indicate any dehiscent fruit, regardless of the number of carpels involved in its formation. The term *legume* applies to the elongated, one-carpelled pods of many members of the family *Leguminosæ,* such as the pea and bean.

The most important of the *indehiscent* fruits (Fig. 80) are:

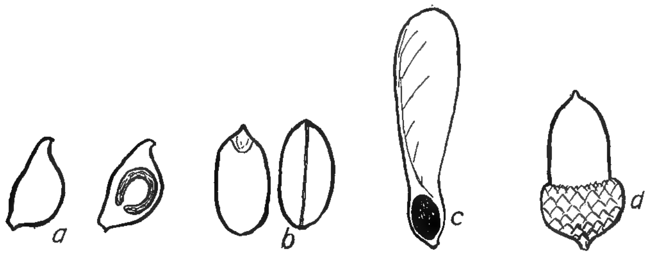

FIG. 80.—Types of indehiscent fruits; (*a*) achene, (*b*) caryopsis, (*c*) samara, (*d*) nut.

(*a*) The *achene* or *akene,* which is a small dry fruit containing a single free pod, such as is produced by the buttercup (Fig. 80, *a*).

The so-called seeds of the strawberry are achene fruits resting on a fleshy torus, each achene being derived from a single pistil.

(*b*) The *samara* or *key* is a fruit a part of which is developed into a thin flat wing, as in the case of the maple (Fig. 80, *c*), ash and elm.

(*c*) The *caryopsis* or *grain* is a fruit in which the mature ovary has united with the seed coats, as in the case of many of the grains, such as corn and wheat (Fig. 80, *b*). These fruits are usually spoken of incorrectly as seeds, but since they are enclosed in the ovary they must be classed as true fruits (see page 120).

(*d*) The *nut* is a fruit with a single seed in which the ovary is usually developed into a hard, bony or horny covering. There are three distinct types of nuts, as follows: the *acorn* type (Fig. 80, *d*), in which the fruit is borne in a cup composed of involucral leaves; the *hazelnut, chestnut* and *beechnut* type, in which the involucral leaves grow around and completely enclose the nuts; and the *hickory* and *walnut* type, in which we are somewhat uncertain as to the origin of the outside structure;

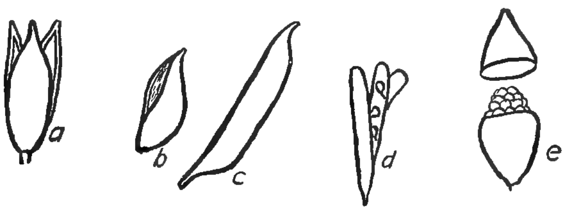

FIG. 81.—Types of dehiscent fruits; (*a*) pod or capsule, (*b*) follicle, (*c*) legume, (*d*) silique, (*e*) pyxis.

the shuck or hull probably consists partly of calyx and partly of involucral leaves.

The most important of the *dehiscent* fruits (Fig. 81) are:

(*a*) The *capsule,* which is a dry, matured ovary, consisting of two or more carpels (*i.e.,* a compound pistil) (Fig. 81, *a*). The capsules open in various ways.

(*b*) The *follicle* is a capsule derived from a single carpel (*i.e.,* simple ovary) and opening along the ventral or upper suture, as in the case of the larkspur and peony, or the dorsal suture, as in magnolia (Fig. 81, *b*).

(*c*) The *legume* is the dry pod or fruit derived from a single carpel and opening along both sutures, as in the bean and pea

(Fig. 81, *c*). This type of fruit is characteristic of the family *Leguminosæ* (page 351).

(*d*) The *silique* is a pod derived from two carpels, which separate at maturity, leaving partition walls, as in the case of the mustard and related plants (Fig. 81, *d*). It is characteristic of the family *Cruciferæ* (page 341).

(*e*) The *pyxidium* or *pyxis* is a capsule which opens by means of a lid, as in the plantain (Fig. 81, *e*).

Seeds.—Seeds are borne within the ovary and should not be confused with fruits. In fact, there is very little reason for confusion except in the case of the indehiscent fruits, especially the achenes and caryopsis, which are usually referred to as seeds. We very generally but incorrectly speak of grains of corn or wheat as seeds, but they are true indehiscent fruits. A knowledge of their structure will make this point perfectly clear to any careful student of botany. We have already studied the formation of seeds in connection with reproduction (page 98), and they will receive further consideration in the next chapter.

SEED DISTRIBUTION

Unless there is some natural method for scattering seeds from place to place any species would remain in a very restricted locality indefinitely. But we know that the range of plants is extended by the scattering of the seeds. If they were not scattered, they would fall directly beneath the parent plant, and the young plants would be so crowded that they could not develop normally. The most common methods are as follows:

(*a*) *Seed Dispersal by the Wind.*—Many seeds possess structures which act as wings or floats by which they are carried for long distances. Some of the common forms with wings are the maples (Fig. 80, *c*), ash and elms, in which the wings are expansions of the ovarian walls. Some other winged seeds are the seeds of the milkweed, catalpa and pine, in which the wings are expansions of the seed coats. Some of the common forms with floats are the dandelion, in which the calyx is developed into a float, and the milkweed, in which the float is developed from the

FIG. 82.—Devices for seed distribution.

seed coat. Some herbaceous plants, when mature, break loose at or near the surface of the ground and are blown across the country, scattering their seed as they go (Fig. 82).

(*b*) *Seed Dispersal by Animals.*—Many seeds, such as burs, beggar ticks, Spanish needles and sticktights, have hooks or other devices by which they become attached to hair and fur of animals and are carried for great distances. Seeds of some other plants, such as those that are enclosed in fleshy fruits and grasses, are eaten by animals and pass through the alimentary canal without being injured. Birds carry the seeds of many fruits and weeds on which they feed, and water fowl carry the seeds of water plants. Squirrels and other rodents store seeds of many kinds, especially nuts, which are frequently not recovered but which grow under favorable conditions (Fig. 82).

(*c*) *Seed Dispersal by Water.*—Some seeds are carried on the surface of streams and lakes, while others are carried by the rapidly running water immediately following rains. Seeds may be carried for short distances over the surface of the ground during periods of heavy rainfall and for great distances on streams, lakes and seas. They frequently lodge along the shores or on distant islands and grow. The vegetation of coral and volcanic islands frequently originates in this manner.

(*d*) *Seed Dispersal by Expulsion.*—Many plants have peculiar mechanical devices by which seeds are thrown to considerable distances. When the witch-hazel pods split open there is a pressure which throws the seeds to a considerable distance. The touch-me-not pods split and curl with sufficient force to throw the seeds a considerable distance. The pods of the common vetch or wild pea split and the two parts twist in such a manner as to throw the seeds out. The so-called "squirting cucumber" absorbs water and shoots the seeds to a considerable distance.

(*e*) *Seed Dispersal by Man.*—Of course, man carries the seeds of his crop plants with him from place to place and in so doing he also carries seeds of many weeds. He also carries the seeds of many plants in bedding for live stock, in packing material, and in the soil about the roots of living plants. Some are carried from country to country in ballast in ships. Seeds frequently fall from railroad trains, grow and become established in new localities.

(*f*) *Government Work.*—Our national government has explorers traveling in different parts of the world in search of economic plants which can be introduced and grown in this country with profit. This work has resulted in the introduction of several new and valuable crops, of which alfalfa, now grown so extensively throughout the greater part of the United States, is an excellent illustration.

LABORATORY EXERCISES.

Exercise 1. Examine an open flower of peach. Note superior ovary and relation of the other parts of the flower to it. From what is the fruit developed? (Preserved material is satisfactory for study.)

Exercise 2. Examine an open flower of apple. Note the inferior ovary and relation of the other parts of the flower to it. From what is the fruit developed? (Preserved material is satisfactory.)

Exercise 3. Examine fruit of the peach and note the exocarp, mesocarp and endocarp. (Preserved material is satisfactory. Small fruits are satisfactory and require less room.)

Exercise 4. Examine the apple and note the calyx at blossom end, and the core or papery endocarp. (Preserved material is satisfactory.)

Exercise 5. Examine blossoms and fruit of blackberries and raspberries if convenient. Note aggregate ovaries.

Exercise 6. Examine strawberries. Note fleshy receptacle and the achenes.

Exercise 7. Examine gooseberry, orange or other berry fruit and note all their parts. From what are they derived?

Exercise 8. Examine a bean or pea pod. Note that it is a simple ovary. Also note the point of attachment of the seeds.

Exercise 9. Examine a number of both fleshy and dry fruits to determine number of carpels and character of placentæ.

Exercise 10. Examine seeds illustrating methods of seed dispersal. Dicotyledonous.

CHAPTER IX

SEEDS AND SEEDLINGS

Seeds.—Seeds are the result of fertilization and are the final product in reproduction. The seed is the most important and last product of the parent plant. It contains the embryo which develops into the seedling or first stage of the next generation. Germination may be considered as the birth of the young plant. Seeds present many superficial differences in size, shape, color and other characters, but may usually be grouped into three different types. The bean, castor bean and corn are good examples of these three different types and have been selected for study. However, it should be remembered that the corn is not a seed but a true indehiscent fruit. We have already learned (page 98) that the seed, regardless of size, shape, color or the species of plant from which it is derived, consists of three parts: (*a*) an embryo or young plant, (*b*) a supply of food which is stored either within the cotyledons of the embryo or as an endosperm or nucellar perisperm immediately surrounding the embryo or both and (*c*) an outside covering consisting of two or sometimes only one seed coat. The value of the seeds as food for man and animals depends primarily on the amount and character of the stored food and the absence of distasteful and poisonous substances.

Bean Type.—This is a dicotyledonous seed in which the food is stored in the cotyledons. An examination of the outside of the bean shows the *hilum* or scar which marks the point of attachment to the pod. Near one end of the scar is a small mark, which is the beginning of an elevated line, the *raphe,* which is formed by the stalk of the ovule. Near the other end of the scar is a minute opening, the *micropyle* (see page 96). Upon the removal of the seed coats we find the embryo or young plant, consisting of the two large, fleshy *cotyledons* or seed leaves, which are attached to a very short stem, and a *plumule* or first bud which is the terminal part of the stem. The part of the stem below the cotyledons is known as the *hypocotyl* and gives rise to the radicle or first root. This seed does not contain either nucellus, perisperm or endosperm (Fig. 83); they having been used in feeding the growing embryo during the development of the seed. Therefore, the cotyledons serve both for the storage of food and as the first leaves of the young plant.

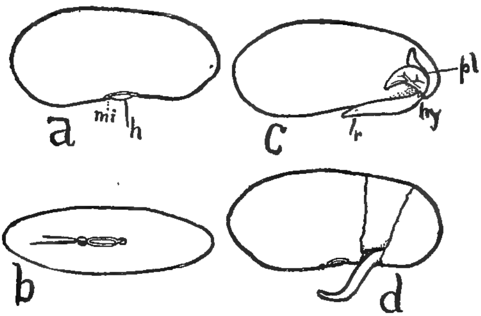

Fig. 83.—Seed of lima bean; (*a, b*) showing micropyle (*mi*) and hilum (*h*); (*c*) with seed coat and one cotyledon removed showing root (*r*), hypocotyl (*hy*) and plumule (*pl*); (*d*) germination.

The embryo is much larger than in most seeds of other types. Other seeds belonging to this type are the pea, peanut, clover, melon, apple, peach, oak, hickory, walnut and cotton.

Germination of the Bean.—In germination, the radicle elongates rapidly, breaks through the seed coats near the hilum and is the first root. The part of the stem below the cotyledons elongates very rapidly and appears above the soil as a loop. The stems straighten and raise the cotyledons above the soil, the seed coats having been pushed off in the soil or soon after the elevation of the cotyledons. The cotyledons spread apart exposing the growing plumule. The cotyledons may develop a green color for a short time, but the food is gradually withdrawn from them to feed the young plant and they finally shrivel and fall away (Fig. 84). The root system is permanent and develops very rapidly.

The Castor-Oil Bean Type.—This is a dicotyledonous seed in which the food is stored in the endosperm (see page 98), sur-

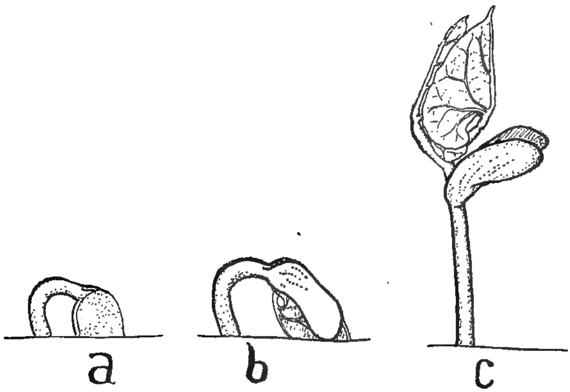

FIG. 84.—Bean seedling coming through the soil.

rounding the embryo. The examination of the outside of the seed shows the hilum at one end surrounded by the *caruncle,* which serves for the passage of water to the inside. Upon the removal of the seed coats we find a compact mass of white, mealy, oily substance which is the endosperm. Between the seed coats and the endosperm is a very thin papery covering, which is the remnant of the nucleus (see page 96). Within the endosperm we find the embryo with its large but very delicate leaf-like cotyledons (Fig. 85). It will be readily seen that in this type of seed the embryo is relatively smaller than in the bean type and that most of the reserve food is stored around the embryo instead of in the cotyledons. The seeds of the beet, tomato, pepper, buckwheat and many of our common weeds belong to this type, but owing to their small size are not so satisfactory for study.

Germination of the Castor-Oil Seed.—This process is very similar to that of the bean, but the cotyledons are covered for

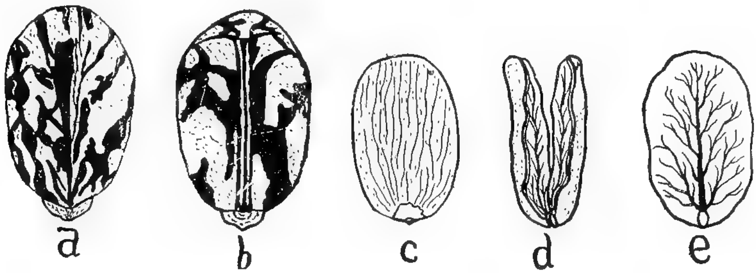

FIG. 85.—Seed of castor-oil plant; (*a*) and (*b*) upper and lower surfaces; (*c*) after removal of the seed coat; (*d*, *e*) cotyledon showing leaf characters.

some time by the endosperm, which they gradually absorb. As the endosperm disappears, the cotyledons become green and more leaf-like and frequently persist for a long time.

Therefore, the cotyledons serve first for the absorption of stored food and later as foliage.

The Corn Type.—This is a monocotyledonous type in which the food is stored in the endosperm. It is not a simple seed, but a true caryopsis fruit (page 112) in which the ovary coats have united with the seed coats. Therefore, it is not strictly comparable to the seeds of the bean and castor-oil bean. It is flattened and somewhat wedge-shaped, the edges rounded and the large end smooth or indented. On one side is a groove within which the embryo is clearly visible. If we cut the grain longitudinally, we find the parts as follows: the *radicle* or primary root lies near the tip of the grain and is enclosed in a delicate sheath; at the opposite end is the *plumule;* the *hypocotyl* or stem is very short and connects the radicle and plumule; attached to the hypocotyl and lying just back of the embryo is the large cotyledon or *scutellum.* The remainder of the grain is made up of the *endosperm,* which in this case is mainly starch but surrounded by the gluten layer. The seed coats and ovarian walls unite to form a thin horny layer (Fig. 86). This is the grass type

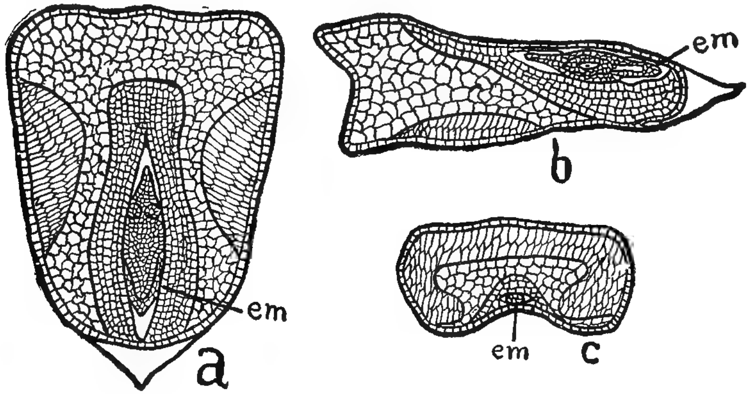

FIG. 86.—(*a*) Diagrammatic under-side view of a grain of corn showing the embryo (*em*) and the layers of food; (*b*) longitudinal section of corn showing same parts; (*c*) cross-section of grain of corn showing the same parts.

of seed and is characteristic of the grasses and many other monocotyledonous plants.

Germination of the Corn.—In germination the root sheath is pushed out for a short distance; this is followed by the emergence of the root tip through the end of the sheath. Two adventitious lateral roots are then formed, one in the axis of the plumule and scutellum and the other on the opposite side of the hypocotyl. Secondary roots are produced from the primary root. The conical roll of leaves emerges from the upper end of the groove. The single *cotyledon* or scutellum functions primarily, if not entirely, as an organ for the absorption of the food supply (Fig. 87). It never emerges and therefore never functions as a foliage leaf.

The Three Seed Types Compared

Bean	*Castor Bean*	*Corn*
A true seed.	A true seed.	A fruit.
Dicotyledonous.	Dicotyledonous.	Monocotyledonous.
Food stores in cotyledons.	Food stored as an endosperm.	Food stored as endosperm and in the nucellus.
Cotyledons serving for storage and as first leaves and then falling.	Cotyledons serving as absorbing organs and as first leaves for a long time.	Cotyledon serving as an organ for the absorption of the stored foods.

Environmental Factors in Seed Germination.—The germination of the seed is the growth of the embryo. In most plants this is preceded by a period of rest. It is dependent on moisture, warmth and oxygen, all of which are absolutely necessary.

The *moisture* requirements which are necessary for germination vary greatly for the different kinds of plants; some, such as corn and wheat, absorbing less than half their weight, others, such as clovers, absorbing more than double their weight. The water penetrates practically the entire seed and softens practically all parts.

Most seeds become swollen by the absorption of water and certain germinating processes are started. The processes are mostly physical and chemical and involve digestion and absorption of food, and growth, waste and repair. They will receive further discussion in Chapters XVIII and XIX.

The temperature necessary for germination is also extremely variable for the seeds of various kinds of plants, the optimum (*i.e.,* the most favorable temperature) ranging from about 75 to 100 degrees Fahrenheit for our garden and farm crop seeds. If the temperature is not the most favorable the rate of germination will be decreased.

Oxygen is also necessary for the germination of seeds. The oxygen is obtained from the air and therefore it is necessary to have the soil loose and the seeds planted at the proper depth.

Processes of Germination.—The processes of germination

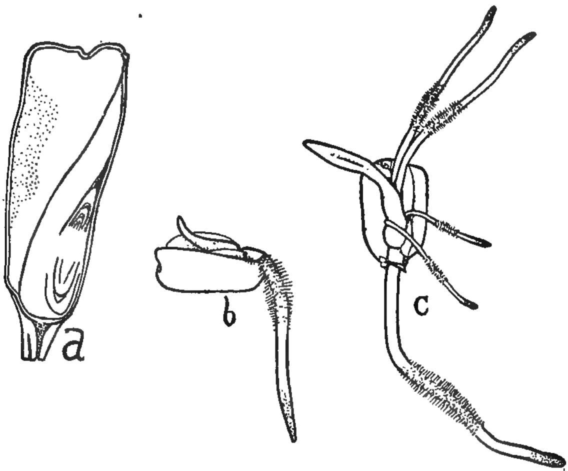

FIG. 87.—(*a*) Longitudinal section of corn seed showing the embryo; (*b*) and (*c*) the germinating seed showing the emergence of the root and plumule, the formation of rootlets and root-hair.

are both physical and chemical. Very briefly, they are the absorption of water, the digestion of the stored foods and the transportation of the same to such parts as may be necessary for growth. The digestion of the food is brought about by specialized substances, known as enzymes, which are also stored in the seeds. The processes of digestion and translocation will receive further discussion in Chapter XVIII.

Utilization of Seeds.—The fact that seeds contain food for the nourishment of the seedlings makes many of them valuable as food for man and live stock. The value of seeds for this purpose depends upon the amount and kind of stored foods, the amount of indigestible materials and the absence of distasteful or poisonous compounds. Beans, peas, wheat, corn and oats are among the most important seeds used for food, but the seeds of many other plants are very important commercially. Peanuts, cotton, castor beans and flax seeds are used extensively for the manufacture of oils and other fatty products.

Longevity of Seeds and Vitality of Seeds.—Seeds vary greatly in their power to resist extremes of temperature, humidity and light and in many other qualities. Some seeds will germinate almost as soon as mature, while others require a period of rest ranging from a few days to a year or longer. In many cases this period of dormancy is dependent entirely on the character of the seed coats. Sweet peas, cannas and other seeds will germinate more rapidly if the seed coats are pierced or scratched so as to permit the entrance of water, and nuts will germinate very quickly if the stony covering is cracked.

Some seeds lose the power of germinating much more quickly than others. The following table shows about the limit of age that some of our agricultural seeds can be used with safety, although much older seeds will sometimes give high percentage germination. Seeds of some plants have been germinated after a storage period of fifty years.

The vitality of the seed varies not only with age but with the manner of harvesting and the storage. It is well known that seeds from weak, diseased and immature plants are likely to be weaker than seeds from healthy, mature plants and mature fruits. Seeds may also be injured by extremes of temperature and moisture in storage. The vitality of some of our important seeds is indicated in the following table:

Tomato	6 years
Melon and pumpkin	5 years
Beans and peas	4 to 5 years
Mustards, cabbage and turnips	3 to 4 years
Alfalfa	3 to 4 years
Clover	2 to 3 years
Corn, wheat, rye and barley	2 years
Buckwheat	2 years
Timothy	1 to 2 years
Onions and celery	1 year

Seed Testing.—The fact that the vitality of the seed is influenced by so many factors makes it very important that seeds used for growing of crops should be tested to determine their power of germination. The national and state governments maintain laboratories for this purpose, but any good grower can make reasonably good tests for germination. A very convenient germinator can be made as indicated in the laboratory exercises.

Purity of Seeds.—Commercial seeds sometimes contain considerable quantity of weed seeds and other impurities. Analyses to determine the amount of impurities are usually made in the seed-testing laboratories and most states have laws controlling the sale of commercial seeds. Some of the important field crop seeds are shown in Fig. 88 and some of the most important weed seeds in Fig. 89.

LABORATORY EXERCISES.

Exercise 1. Examine a good sized bean seed and note the hilum, raphe and micropyle. Remove the seed coats and note the large cotyledons, plumule and hypocotyl.

Exercise 2. Germinate beans in wet moss so as to get long, straight primary roots. When the roots are about three-quarters of an inch in

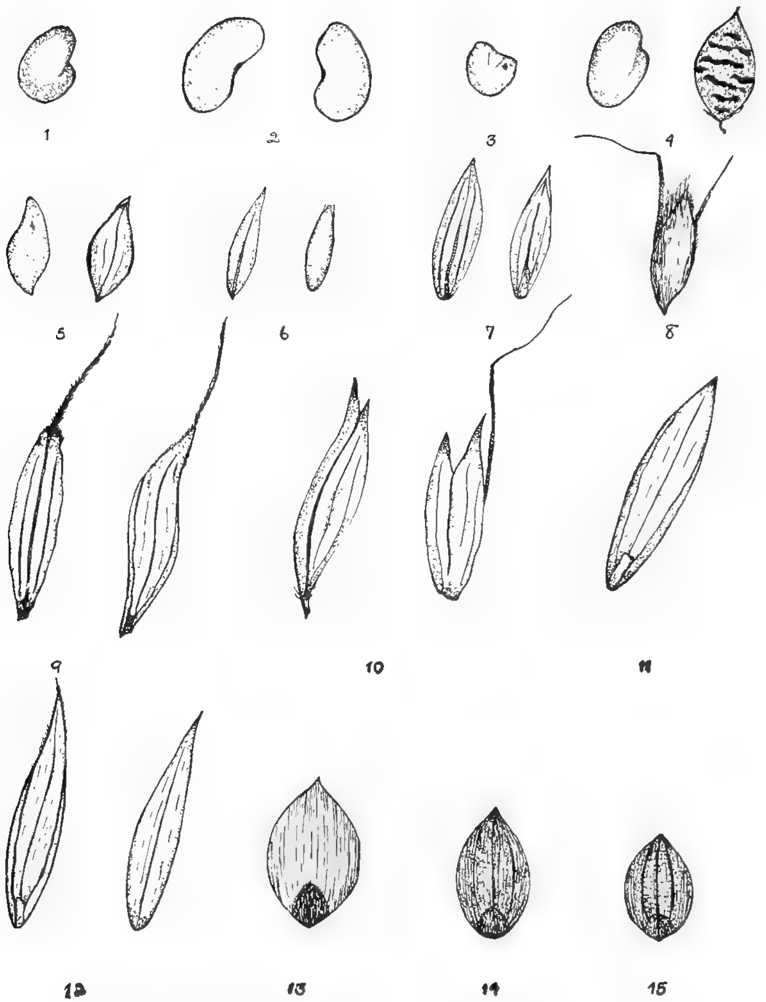

FIG. 88.—Crop seeds: 1, red clover; 2, alfalfa; 3, alsike clover; 4, sweet clover; 5, timothy; 6, red top; 7, Kentucky blue grass; 8, sweet vernal grass; 9, annual rye grass; 10, tall meadow oat grass; 11, English rye grass; 12, orchard grass; 13, broom corn millet; 14, Hungarian millet; 15, German millet.

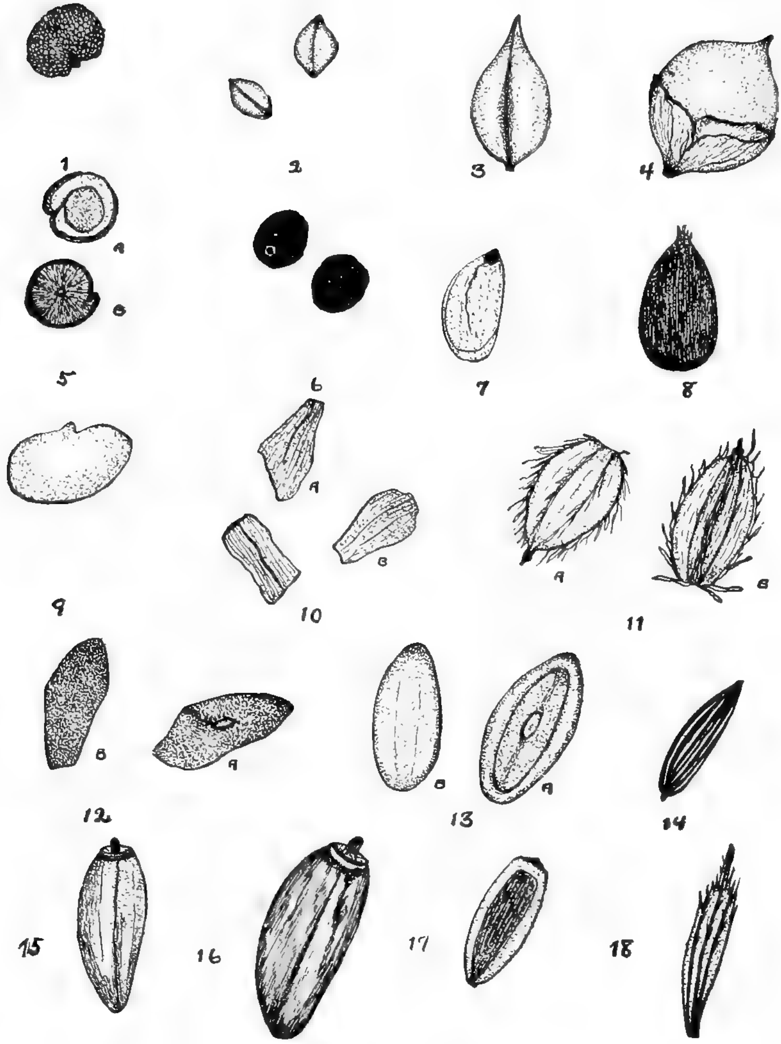

FIG. 89.—Weed seeds: 1, Night-flowering catchfly (*Silene erectifolia*); 2, sheep's sorrel (*Rumex acetosella*); 3, curled dock (*Rumex crispus*); 4, Pennsylvania smartweed (*Polygonum pennsylvanicum*); 5, lamb's quarter (*Chenopodium album*); 6, tumbling pigweed (*Amaranthus retroflexus*); 7, peppergrass (*Lepidium virginicum*); 8, field cress (*Lepidium campestre*); 9, yellow trefoil (*Medicago lupulina*); 10, evening primrose (*Onagra biennis*); 11, wild carrot (*Daucus carota*); 12, Rugel's plantain (*Plantago Rugelii*); 13, buckhorn (*Plantago lanceolata*); 14, ox-eye daisy (*Chrysanthemum leucanthemum*); 15, Canada thistle (*Cnicus arvensis*); 16, bull thistle (*Cnicus lanceolatus*); 17, yarrow (*Achillea millefolium*); 18, dandelion (*Taraxacum officinale*); (*a*) ventral side; (*b*) dorsal side. 1, Caryophyllaceæ; 2-4, Polygnaceæ; 5, Chenopodiaceæ; 6, Amaranthaceæ; 7-8, Cruciferæ; 9, Leguminosæ; 10, Anagraceæ; 11, Umbelliferæ; 12-13, Plantaginaceæ; 14-18, Compositæ.

length, mark one or more with India ink (using a fine pen or brush or thread) into sections of about one-sixteenth of an inch. Wrap the seed in wet cotton and insert the root into the tube of a glass funnel. Cover the funnel with a plate of glass to prevent evaporation and set in a dark place. Examine from time to time and determine region of greatest growth.

Exercise 3. Seal the micropyles of a few lima beans with a quick-drying varnish. Germinate in wet moss with untreated seeds. Compare time required for germination of seeds in which the micropyles were not sealed.

Exercise 4. Examine the seed of a castor-oil plant and compare with the bean. Note the caruncle. Remove the seed coats and note the stored food. Examine the cotyledons and other parts of the embryo and compare with the bean.

Exercise 5. Examine a grain of corn and compare with the bean and seed of castor-oil plant. Note the groove with the embryo lying just below the coverings. Remove the embryo from one grain; cut another grain longitudinally. Note the plumule, radicle, hypocotyl, scutellum (cotyledon) and relation of embryo to the stored food.

Exercise 6. Scrape the ovary and seed coats from one side of a few grains of corn. Germinate with uninjured grains. Compare time of germination. Explain.

Exercise 7. Germinate beans, seeds of castor-oil plant and corn in loam soil and compare germination and growth.

Exercise 8. Examine and germinate seeds of as many other plants as may appear desirable.

CHAPTER X

CELL DIVISION

We have already learned that the growth of the plant involves an increase in number and size of the cells. In many of the lower plants this division is by a very simple process, but in the higher plants it is the result of a very complicated process known as *mitosis.*

The term "mitosis" is used to designate the complicated internal processes of cell division. We have already studied the structure of the cell (Chapter I). The *protoplasm* is the living part of the organism and can be divided into the *cytoplasm* or constructing part, the *plastids* (Chapter I) and the *nucleus* or controlling part.

The *nucleus* is composed of the *chromatin,* which is a tangled thread of colorless substance that absorbs artificial stains very readily, and is considered its most important part; the *nucleoli,* and the *linin,* which is a network of very delicate threads.

The first evidence of cell division (Fig. 90) is the enlargement of the nucleus which contains the *linin* (or the network of delicate threads) the *nucleoli* and *chromatin.* The chromatin is very definitely associated with the linin. It increases in amount, becomes ribbon-like in character and finally divides into short pieces called *chromosomes.* Their number is constant for each species, but varies in the different species of plants. At about this time the nuclear walls disappear and delicate colorless strands appear and take the form of a *spindle* which is composed of two parts, the outer and inner series.

The lines of the spindle have very much the same appearance as the meridian lines on a globe. The chromosomes become more or less V-shaped and collect at the equator with their points directed towards the center. Each chromosome divides longitudinally into two apparently equal V-shaped structures (Fig. 90).

This gives double the number of chromosomes, one-half of which travel towards one pole and the other half towards the

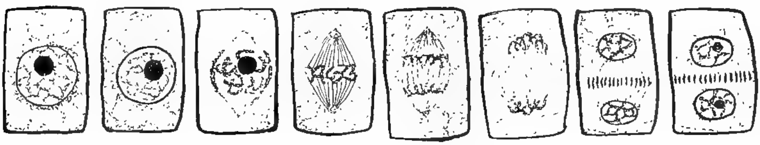

FIG. 90.—Stages in the mitotic divisions of the cell.

other. These two groups of chromosomes become the nuclei of the two new or daughter cells. The strands of the inner spindle become thickened at the equator and develop into a wall separating the two new cells.

Certain ones of the new cells retain their meristematic character and divide again, while other cells enlarge and develop into the elementary tissues which we have studied in Chapter II.

The preceding discussion is very general. There are many modifications, but only a few can be discussed in a work of this kind. Nuclear divisions without the formation of cell walls sometimes occur in the formation of the endosperm in the embryo sacs of some plants.

In some cases, especially in old cells, the division is direct instead of being preceded by the mitotic division of the nucleus.

In *reproduction* the chromosomes of the male nucleus enter the nucleus of the egg. Therefore, the fertilized egg contains chromatin from both parents. This union of chromatin is believed to be the basis of heredity.

REDUCTION DIVISION

Let us now return to the discussion of fertilization and apply the principles of cell division to fertilization. It has been said that after mitotic cell division each new cell has the same number of chromosomes as the parent cell possessed. There is one important exception to this rule: it can readily be seen that if an egg and a sperm each possessed the full number of chromosomes, the cell formed by their union would have twice the regular number. If this fertilized cell grew into a plant and reproduced in the same way and the same procedure continued for a few generations, the number of chromosomes in a single cell would soon become impossibly great. This result is avoided by a special kind of cell division called the "reduction division" in which the number of chromosomes is reduced by one-half. In animals the reduction division takes place immediately preceding the formation of the eggs and sperms, so that these have the single or haploid number of chromosomes and the new organism formed by their union has the double or diploid number. In plants exhibiting the phenomenon of alternation of generations the reduction division immediately precedes the formation of the spores. The spores thus possess the haploid number of chromosomes as do the gametophytes to which the spores give rise, hence, in the formation of the gametes, the eggs and sperms, no further reduction is necessary. The sporophyte, resulting from the union of an egg and a sperm, has, of course, the diploid number of chromosomes. The relationship of this process to inheritance of characters will be given further consideration in Chapter XXI.

LABORATORY EXERCISES.

Exercise 1. Examine slides of root tips of onion or other plants showing mitosis. Study carefully and make drawings showing the different stages.

Exercise 2. Examine prepared slides of material (anthers of flowering plants or sporangia of ferns), showing reduction division. Study carefully and make drawings of as many stages as possible.

CHAPTER XI

PLANT PRODUCTS

Plants produce a great many compounds, some of which become permanent structures in the plant, others are used directly in the processes of growth, others are stored for use by the plant at some future period and still others are believed to be by-products or waste so far as the welfare of the plant is concerned. Many of these plant products have been utilized by man for foods, clothing, building, fuel, drugs and other purposes. The products include both the cell walls and cell contents. The cell contents may be divided into the protoplasmic and non-protoplasmic products.

Protoplasmic cell contents are the protoplasm, nucleus and plastids which have already been considered (see Chapter I).

Non-protoplasmic cell contents are (1) those of a definite form, including (*a*) the colloidal or crystalloidal products, such as starch and inulin; (*b*) the crystalline products, such as sugars, alkaloids, glucosides and calcium oxalate; the composite bodies, such as aleurone grains, which are composed of different compounds; (*c*) those of a more or less indefinite form, such as tannin, gums, mucilages, fixed and volatile oils, resins, gum-resins, oleo-resins, balsams, caoutchouc, silica and calcium carbonate.

"*Starch* is the first visible product of photosynthesis" (see page 195), although it is no doubt preceded by the formation of sugar. Starch grains are formed within the chloroplastids, but they sometimes become so large as to break the covering membranes of the plastids. Starch may be made soluble by the action of enzymes and transported to other parts of the plant for immediate use as food or for storage for future use. The form and structure of the starch grains varies in different species of plants and in different parts of the same plant. The most generally accepted formula of starch is $(C_6H_{10}O_5)_n$, but it has been shown that it is in reality made up of two substances. Starch grains are ovoidal or spherical or polygonal and show a more or less distinct point or origin of growth known as the *hilum*. The two substances are laid down in more or less distinct layers. The starch grains are usually single, but may be formed in groups of two or three or four or in the case of some of the cereals of 100 grains. Starch is slightly soluble in water and gives a blue or blue-black color when treated with iodine. It can be transformed by heat, by enzymes, and by dilute acids into dextrin (Figs. 91, 92, 93, 94).

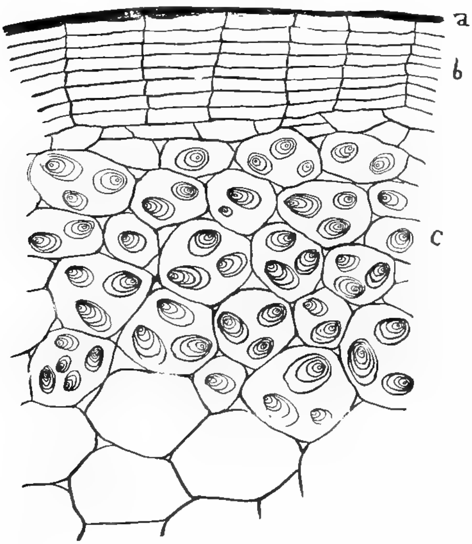

FIG. 91.—Section of potato showing (*a* and *b*) the epidermal layers of cells; (*c*) the inner cells and starch grains.

Starch is one of the most important of the plant products. Although it is manufactured in the green parts of the plant, it is stored in practically all parts of the plant. It is found in considerable quantities in stems and roots, especially at the close of the season, but is found in greatest abundance in such special storage organs as bulbs, tubers, fleshy roots and seeds. It is found in very great abundance in fruits, and is the most abundant food compound in all nature. It is used more extensively than any other food product.

The percentages by dry weight of starch in some of our most important food plants are as follows: potatoes, 80 per cent.; wheat, 68 per cent.; rice, 68 per cent.; corn, 60 per cent.; pears, 52 per cent., and navy beans, 45 per cent.

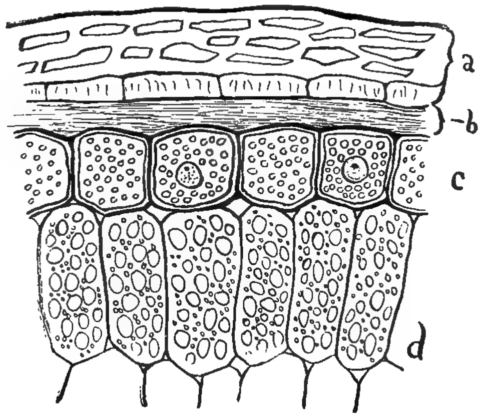

FIG. 92.—Section of grain of wheat: (*a*) ovary coats, (*b*) seed coats, (*c*) layers of cells containing aleurone, (*d*) cells containing starch.

Inulin is an isomer of starch which is found in solution in the cell sap of many plants and is readily crystallized by alcohol (Fig. 95). It is abundant in the underground organs of many plants, especially the roots of the dahlia (Fig. 95). Although of some importance to the plant, it is of very little importance as a food for animals.

The *sugars* are the products of photosynthesis and are very abundant and very widely distributed crystalline compounds. They are very closely associated with starch, into which they are readily converted. They are also very readily reconverted into sugars. The most important sugars are as follows:

(*a*) *Dextrose* (grape sugar or *dextrose-glucose*) is found in the nectaries of flowers and in fruits, varying from one or two per cent. in peaches to thirty per cent. in some varieties of grapes. It also occurs in combination-forming glucosides. Glucose is the first definite carbohydrate product of photosynthesis.

(*b*) *Levulose* (*fructose,* fruit sugar, or *levo-glucose*) is associated with dextrose and may occur in larger quantities.

(*c*) *Sucrose* (*saccharose,* or cane sugar) is widely distributed, occurring in the stems of corn, sugar cane and related plants; in the roots of some plants, notably of the sugar beet; in the cell sap of some trees, notably of maples and palms; in the nectaries and sap of some flowers; in some seeds, such as the almond and chestnut; and in many fruits. This is the most important commercial form of sugar, and is obtained most abundantly from sugar cane, sugar beets and maple trees.

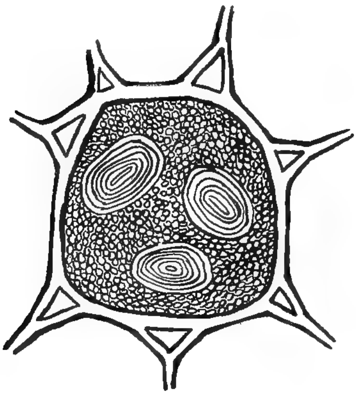

FIG. 93.—Cell from pea containing starch and aleurone.

(*d*) *Maltose* is formed in seeds, more especially the cereals during germination.

It will be readily seen that we secure a great deal of sugar as food from the ripe fruits that form such an important part of our diet. However, man has learned to extract the sugar from the sap of many plants, such as sugar cane, sugar beet and maple trees. Sugar is easily digested and is a very important compound in our food supply.

Hemi or *reserve celluloses* are very hard plant products (mannans and galactans) which are very similar to true cellulose. They are deposited on the inner surfaces of the walls of cells and are very readily transformed into sugars. They give the hard, horn-like character to coffee and date seeds and are important foods in the germination of these seeds.

The *alkaloids* are supposed to be formed in the protoplasm, but are later found in the cell sap in combination with the various plant acids. They contain nitrogen, carbon, hydrogen and sometimes oxygen; they will combine with acids and form salts. They are usually associated with starch, fixed oils, aleurone grains and other reserve food products. They may be abundant in immature fruits and seeds, but they disappear with maturity. Many of the alkaloids are very poisonous. Among the most important are the following:

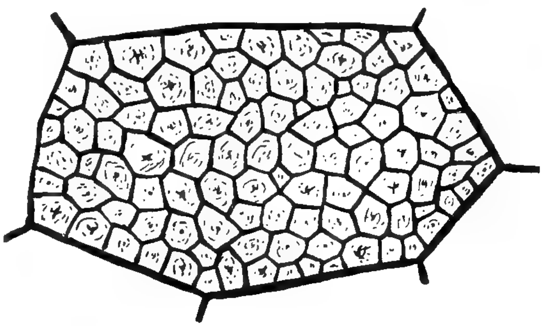

FIG. 94.—Cell from grain of corn containing starch.

(*a*) *Theine,* from tea; 1 to 3 per cent. in dry leaves.

(*b*) *Caffeine,* from coffee; .5 to 2 per cent. in the bean.

(*c*) *Theobromine,* from cacao, or chocolate plant; 1.5 per cent. in the seeds.

All of the above are in general use, but are poisonous and injurious to health when used in large quantities.

(*d*) *Morphine* and a number of other alkaloids from the opium poppy are used in medicine. The smoking of opium has most deleterious effects on both body and mind. Opium and its derivatives should never be used except when prescribed by a physician.

(*e*) *Nicotine* of tobacco is one of the most violent poisons. However, it is used for its effects on the nervous system more than any other drug. It has been estimated that more than 800,000,000 people make use of it for this purpose. Its effects vary greatly with the age, nervous temperament and habits of the user. However, it is very generally conceded by all who have made a scientific study of the subject that it is always injurious.

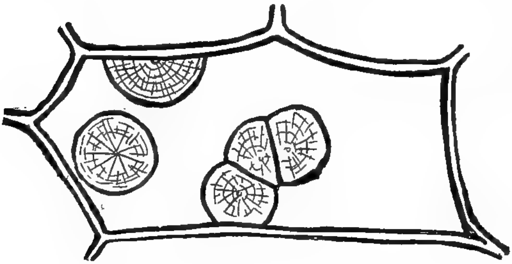

FIG. 95.—Sphæro-crystals of inulin.

(*f*) *Atropine* of the belladonna plant is used to some extent in medicine.

(*g*) *Quinine* from the cinchona tree is very extensively used in medicine.

(*h*) *Strychnine* from the nux vomica tree is a most violent poison which is used to some extent in medicine.

The *glucosides* are probably formed by the protoplasm. They are compounds of glucose and other substances and may be either nitrogenous or non-nitrogenous. They are bitter to the taste and some of them undoubtedly serve as reserve food materials. They are very numerous and among the most important are: (*a*) *amygdalin* of the bitter almond, (*b*) *solanin alkaloid* of the Solanaceæ, (*c*) *salacin* of the willows, (*d*) *coniferin* of the Conifers and (*e*) *digitalin* of the Digitalis or Foxglove.

The *pigments* are the coloring products found in the cell sap or in the chloroplasts and chromoplasts. Their origin and their functions in most cases are not definitely known. *Chlorophyll* appears to be the most important and is usually formed in the chloroplasts.

The function of chlorophyll in the formation of carbohydrates, the very first step in the making of true foods, has been referred to (page 17) and will receive further consideration in Chapter XVI.

Carotin and *xanthophyll* are always associated with chlorophyll. The various colors of flowers, fruits, leaves and other parts of the plant are dependent on these pigments.

Calcium oxalate is found in many plants and is readily seen in various crystal forms. Many other compounds crystallize in plants and may be very generally recognized by their forms.

Many *acids* are found in plants, especially in the fruits, or are derived from plant products by fermentation. Among the most important are *malic acid, oxalic acid, citric acid, tartaric acid, tannic acid* and many others, especially the fruit acids, which in a great measure determine the flavor and quality of our edible fruits.

Proteins are essential to the formation of living protoplasm and, therefore, may be considered the most important of the plant products. They are probably formed in the leaves in a manner somewhat similar to photosynthesis, although light is not a direct factor in their formation. Their exact chemical composition is not known, but they are known to be very complex and to contain carbon, hydrogen, oxygen, nitrogen, sulfur, and usually phosphorus. They may be classified in three principal groups, dependent primarily on their solubility, as follows: (*a*) the *simple* vegetable proteins, including the albumins of seeds and cell sap, which are mostly soluble in water; (*b*) the *conjugate* proteins, so called because of the association of nucleic acid and protein as in nucleo-proteins. They are important constituents of the nuclei. (*c*) The *derived* proteins, which are the digested and diffusible protein products (proteoses and peptones), which are necessary in assimilation. The proteins are found throughout the plant, but are usually most abundant in the seeds. Most of the proteids can be digested in the animal body by the enzymes, pepsin and trypsin.

The proteins are very abundant in certain plants, especially the legumes, and in the seeds of the grain plants. The most important kinds of proteins are: (*a*) the *albumins,* found in beans, peas and cereals; (*b*) the *globulins,* found most abundant in legumes; (*c*) the *glutenins,* found in cereals, especially in wheat and rice; (*d*) the *gliadins,* found in the cereals; and (*e*) the *nucleo-proteins,* found in the nucleus. Most of the proteins are insoluble in the cell sap of the plant and must be digested, that is, made soluble, before they can be used or moved. This is accomplished by the action of enzymes in a manner similar to that in the animal stomach and results in transformation into peptones, proteoses and similar soluble products. They are a very important and necessary part of our food supply.

Amides are simpler than the proteins. They are composed of carbon, hydrogen, oxygen and nitrogen and are soluble in the cell sap. They are reserved foods and are found in the underground parts of the plant. Among the most important are *asparagin, glutenin, trypsin* and *leucin.*

Tannin and *tannoids* are astringent products which are used in the manufacture of leather, in medicines, etc. They are obtained primarily from the bark and woody parts of our higher plants.

The *mucilages* and *gums* are formed within the cell or by modification of the cell wall. Many of them are of considerable commercial value. Among the most important of the vegetable gums of commerce are gum camphor, gum-arabic and gum-tragacanth.

The *oils* and *resins* are formed by the protoplasm and are associated with the mucilages and tannins. There are two classes of oils: (1) The reserve or fixed oils, which are also known as fatty oils and are associated with fruits and seeds. Among the most important are olive oil, corn oil, cotton-seed oil, cocoanut oil, flax or linseed oil and castor oil. (2) The volatile oils, which are found in specialized secretory cells or canals. They are important factors in the odors of plants and many of them are extracted for commercial purposes. Among the most important are: oil of peppermint, oil of sassafras, oil of cinnamon, oil of cloves, oil of cedar, and oil of bergamot from the orange rind. The pine resins, india rubber, gutta-percha and camphor are related to the volatile oils and are well-known commercial products.

Fats and *fatty oils* are not soluble in water or cell sap. The vegetable fats are found in the form of minute crystals in the cytoplasm and the fatty oils as very fine emulsions. They are both found in the plants as mixtures of glycerine esters or glycerides of palmitic, stearic and oleic acids and are called *palmitin, stearin* and *olein.* The first two are solid at ordinary temperatures and the latter is fluid. They are most abundant in the seeds of plants and serve as important reserve foods in germination. Some of the most important sources of commercial oils are castor beans, flax seed, rape seed, cotton seeds, peanuts, olives and cocoanuts. The edible nuts are very rich in oils.

The volatile oils are secretory products and differ from the fats and fatty oils in being volatile but are also different chemically. They are the causes of the odors and flavors of many plants, such as the peppermint, sassafras, spice bush, cloves, cinnamon, cedar wood and orange rind. They also are the causes of some of the odors in flowers and may be important factors in attracting insects and assuring insect pollination. The oils of these and many other plants are important commercial products and are used extensively in the manufacture of perfumes and the various essences used in the preparing of foods, medicines, etc.

The *resins* are secretory products which are very similar to the volatile oils. They are secreted very abundantly in the resin tubes, which are formed in the wood of pines and other coniferous trees. Pitch, turpentine, pine tar and rosin of commerce are derived from pine resins. India rubber and gutta-percha are manufactured from plant juices which are very similar to the volatile oils and are obtained from many different plants.

The *enzymes* are developed from the protoplasm of the living cells and are similar in chemical composition to the proteins. They have the power of causing chemical changes in other compounds without being used up or undergoing any changes which we can detect. They are found in both plants and animals, and are very important factors in the life processes of the plant. Some of the more important are the *diastases* which change starch into sugar, the *invertases* which change cane sugar into dextrose and the *proteolutic* which digest the proteids. They may be divided into two groups: (1) the *oxidase enzymes* which require oxygen and (2) the *hydrolytic enzymes* which require water for their activities.

Cell Wall.—We have already learned that the cell wall is composed of cellulose which may be modified into *lignin* (wood cells) or into *suberin* (cork cells), by impregnation with various compounds. These various modifications which plant cells undergo make the wood or other cell wall structures useful for various commercial purposes. The best grade of cellulose is used in the manufacture of paper and celluloid. The suberized structures in woody plants have many uses in commerce. The variations of cell structures give the great varieties of woods which are a study in themselves. Cotton and linen goods, ropes, carpets and numerous other manufactured products illustrate the many and diverse uses of plant fibers. Among the most important fiber plants are cotton, flax, hemp, jute, manila hemp and sisal. The study of vegetable drugs and drug plants is another extensive line of work which can only be referred to at this time.

The value of our forests for lumber, which is used in so many ways, and for fuel is very generally recognized and has given rise to that very important part of botany known as forestry. However, it is not so generally recognized by many people that the great beds of coal have been derived from ancient forms of vegetation, mostly moss plants and ferns or fern-like plants.

LABORATORY EXERCISES.

Exercise 1. Examine a thin section of potato from near the center of the tuber. Note the large cells, thin walls and starch grains. Add a drop of weak iodine and again note the starch grains.

Exercise 2. Examine another section cut so as to show the cells near the surface. Note how these cells differ from those in the interior. Add a drop of weak iodine and note the yellowish tint of the crystalloids which indicates their nitrogenous character.

Exercise 3. Repeat 1 and 2, using fleshy roots of various plants and fruits of apples and other plants. Compare with 1 and 2.

Exercise 4. Examine a section of a cotyledon of a pea. Note the starch grains and compare them with those of the potato. Also note the very small aleurone grains in the same cells as the starch grains. Add a drop of weak iodine and note the yellowish tint of the crystalloids and compare with 2.

Exercise 5. Repeat No. 4, using bean seeds.

Exercise 6. Examine a cross-section of a grain of wheat (mount the section in glycerine). Note the seed and ovary coats, the starch grain and the aleurone in special cells ("gluten sacs") near the outside. Compare with potato and pea.

Exercise 7. Examine the starch from the semi-transparent part of a grain of corn. Compare with the preceding.

Exercise 8. Examine the starch from a grain of oats. Compare with the preceding.

Exercise 9. Examine a fragment of lamina (scale) of an onion. Note the crystals, mostly calcium oxalate and some few calcium carbonate.

Exercise 10. Examine a cross-section of a leaf of a rubber plant (*Ficus elasticus*). Note the large crystals (Cystoliths).

Exercise 11. Examine a thin section of Dahlia root that has been preserved in glycerine or strong alcohol. Note sphærocrystals of inulin.

Exercise 12. Examine thin sections of rhubarb and note the calcium oxalate crystals.

Exercise 13. Make a solution of glucose in a test tube; add Fehling's * solution and heat. Describe the reaction.

Exercise 14. Make a solution of cane sugar in a test tube. Add Fehling's* solution. Compare with Exercise 13. Add a few drops of hydrochloric acid, boil, neutralize with KOH (to litmus) and repeat the Fehling's test. Compare with Exercise 13.

Exercise 15. Put 10 grams of ground malt into 100 cc. of cold water. Shake, allow to stand for four hours and filter. The liquid is an extract of diastase.

Make a thin paste of starch and hot water. When cool, put 10 c.c. into each of four tubes. Add 5 c.c. of diastase extract to two tubes and keep at a temperature of about 60 degrees C. for a few hours. Test one of each for starch with iodine and one of each for sugar with Fehling's solution.

Exercise 16. Soak pieces of beets in warm water. Test the liquid with Fehling's solution. Does it contain sugar?

Exercise 17. Test several fruits for both starch and sugar.

Exercise 18. Fats and Oils. Soak bean and castor-oil bean in water. Cut sections and examine for oil; soak in mixture of equal parts of absolute alcohol and ether; note the effect. Stain newly cut sections in a 50 per cent. alcohol solution of cyanin for 30 minutes and examine.

Exercise 19. Crush some castor beans, tie in a cloth and soak in xylol or benzine. Squeeze out and remove. Pour the xylol or benzine into a dish and allow to evaporate. The oil remains in the dish.

Exercise 20. Cut thin sections of a nut and examine under the microscope. Note the oil drops in the cells.

Exercise 21. Tie a small quantity of wheat flour in a bag and knead under a stream of water. The sticky dough that remains is largely protein. The starch was mostly washed out by the stream of water.

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*Fehling's solution (A)—Dissolve 35 grams of copper sulphate in 500 c.c. of water. (B)—Dissolve 60 grams of caustic soda and 173 grams of sodium potassium tartrate in 500 c.c. of water.

Use equal parts of A and B, but do not mix until needed.

Exercise 22. Test some of this protein with fresh Millon's reagent and note the effect.

Millon's reagent.—Dissolve mercury in an equal amount (by weight) of nitric acid. Dilute this solution with an equal amount of distilled water. It must be used fresh. Protein treated with this reagent turns brick red.

Exercise 23. Cut thin sections of wheat grains to show protein. Add a drop of fresh Millon's reagent and note the effect.

Exercise 24. Treat cotton fibers with chloro-zinc-iodine under cover glass and note the effect. The blue color indicates cellulose.

Exercise 25. Cellulose. Cut sections from the interior (endosperm) of a date seed. Note the character of cellulose walls. Treat as in 24.

Exercise 26. Melt the tip of a stick of sealing wax and attach a flax seed. Cut sections. Examine under the microscope. Add water and note the effect. These cells are mucilaginous. The mucilage is a decomposition product of cellulose.

Exercise 27. Cut sections of stems or other parts of plants and examine under the microscope. Put a little chloro-zinc-iodine under the cover glass. A blue color indicates that the cell walls are not liquefied or cutinized.

Chloro-zinc-iodine.—Dissolve 25 parts of zinc chloride and 8 parts of potassium iodide in 8½ parts of water and add enough iodine to give a dark color.

Exercise 28. Mount woody sections in aniline chloride and run a few drops of hydrochloric acid under the cover glass. A yellow color indicates lignin.

PART II

PLANT ACTIVITIES

HAVING studied the construction of the plant as a machine, we will now study the working of the machine, or the physiology of the plant. This involves the taking in of water and soluble salts from the soil and gases from the air; the absorption of the energy of sunlight; the response of the plant to its environment; the many and various processes of growth and reproduction; and the giving off of waste materials.

CHAPTER XII

THE PLANT AS A WORKING MACHINE

The Plant is a Living Machine.—We have learned that the cell is the structural and physiological unit of the plant. In the lower forms of plants the cell is undifferentiated and capable of performing *all the functions* of plant growth and reproduction. But as we study the higher plants we find a differentiation of the cells into tissues, systems and organs accompanied by a corresponding physiological division of labor. We have studied the cells, tissues, systems and organs in the preceding chapters and have learned that the higher plants are very complex mechanisms. We will now study the very complex workings of this mechanism. This phase of the subject is known as *plant physiology.*

The Physiology of the Cell.—The functions of the cells in the various parts of the plant vary with its structure. The cells of the stem serve primarily for support and transportation of foods, those of the roots for absorption of water, and those of the leaves for absorption of carbon dioxide, transpiration of water and photosynthesis. Transportation of food depends on the character of the cell wall and the contents of the cell; absorption depends on the character of the cell contents; photosynthesis depends on the presence of chlorophyll in the cell. But there are many other characters and functions, in addition to these well-known functions, such as the organization of starch grains by the amyloplasts or leucoplasts; the making of proteins, fats and oils; the processes of metabolism; growth and reproduction.

The plant differs from the ordinary machine which is the product of man's skill in that it is a living, growing machine and is capable of making its own repairs and of reproduction; *i.e.*, of producing new individuals like itself. It is an automatic machine and its workings are very imperfectly understood. In order to grow and reproduce itself it must take in water, carbon dioxide, minerals, nitrogen, etc., and transform them into parts of itself. This involves very complex physical, chemical and physiological activities.

Although we are accustomed to think of these activities in connection with the plant as a whole, we should remember that they are the properties of the individual cells; that the cell is the physiological as well as the structural unit of the plant. The most important of these are: (*a*) *Absorption*, which involves the taking in of water and gases—the water-soluble materials are usually taken in through the roots (page 155) and the gas is taken in mostly through the leaves (page 193); (*b*) *photosynthesis*, which is the making of carbohydrates (page 195); (*c*) *transpiration*, which is the giving off of water and gases, mostly through the leaves (page 170); (*d*) *metabolism*, which involves the digestion of foods; the breaking down of parts of the plant (or machine); the elimination of waste; translocations of food materials, true foods and waste; and growth (Chapter XVIII); (*e*) *contraction*, expansion and response to external stimuli; and (*f*) *reproduction*, which involves the formation of new individuals.

Plant Foods.—We are accustomed to speak of water, mineral salts and carbon dioxide as plant foods, but this is not strictly true. We cannot conceive of the animal living on these compounds. The animal lives on carbohydrates, fats, oils and proteins which it obtains from the plant. The green plant feeds and lives on exactly the same compounds as the animal, but, unlike the animal, it must first manufacture these compounds for itself from the water, carbon dioxide and mineral salts, as will be explained in the succeeding chapter. Therefore, it will be readily seen that the green plant is dependent on water, carbon dioxide, character of soil, temperature and sunlight for its existence; but the animal is dependent upon the plant for its existence. In brief, green plants take the water, carbon dioxide, nitrogen and minerals which we may consider as crude or raw foods and manufactures them into carbohydrates, fats, oils and proteins, which we may consider as true foods; both plants and animals use the same compounds, carbohydrates, fats, oils and proteins, for their growth; animals and non-chlorophyll-bearing plants, such as fungi (page 273), are dependent on the green plants for their foods. The taking in of raw or crude foods, the manufacture of true foods, growth, waste, repair, reproduction and behavior will be given consideration in following chapters.

Gases, Liquids and Solids.—The crude foods are in the form of gases, liquids and solids, and the true foods in the form of liquids and solids. Therefore, it is necessary to know something about the nature of these forms of matter.

A *gas* is composed of very small particles which tend to separate indefinitely and if unconfined may become far separated and intermingled with other gases. A gas may be dissolved in another gas, in a liquid or in a solid.

A *liquid* is composed of particles which are much less mobile than those of the gases. It will shape itself to its container and give off particles to the air as vapor. A liquid may be soluble in another liquid.

A *solid* is also composed of particles, but is much less mobile than a liquid, and it retains its form more or less perfectly. Some solids are soluble in liquids and some are soluble in other solids. Some may be liquefied and then vaporized.

Solution.—All gases, liquids and solids are made up of particles, and when the particles of two are brought in contact they usually tend to intermingle to a greater or less degree; *i.e.*, one is dissolved by the other. Gases are very generally dissolved in liquids, the liquid being the *solvent* and the gas the *solute*. Many solids are dissolved in liquids; the liquid being the solvent and the solid the solute. Some liquids are dissolved in others; *e.g.*, glycerine in water, the water being the solvent and the glycerine the solute. Some liquids, such as oil and water, will not intermingle. In some cases a solid is dissolved in a measure by another solid, but the process is always very slow; *e.g.*, the particles of lead and gold, if kept in contact for a long period of time, will intermingle very slowly.

CHAPTER XIII

THE RELATION OF THE PLANT TO WATER

Water Content.—The living plant contains a very high percentage of water which can be readily determined by weighing the fresh plant, drying it thoroughly in an oven and then weighing a second time. The amount of water varies greatly in different plants and also in different parts of the same plant. The soft, succulent plants, the fleshy parts of many plants, and the fruits of many plants contain high percentages of water as compared with the hard and woody parts of plants and the mature seeds and grains. In fact, most of our vegetable foods are made up almost entirely of water. The following table will give some idea of this great variation of water content:

Plant	Percentage of Water
Cucumber, fruit	96.00
Beets, roots of mangel-wurzels	90.00
Cabbage heads	90.00
Beets, red	88.00
Sugar beets	86.50
Cow peas, hay, green	83.60
Corn fodder, green	79.08
Potatoes, Irish	78.90
Potatoes, sweet	71.10
Rice, grain	12.60
Oats, grain	11.00
Corn, grain	10.90

It will be readily seen that the water content in different parts of a plant varies; the ripe fruit of the tomato will certainly contain more water than the stem and leaves. The ripe fruit of a watermelon will likewise contain more water than the seeds or the stems and leaves. These and many other illustrations that might be given lead us to believe that *there must be some very complex structural and physiological factors which influence and control the amount of the water contained in the different parts of the plant.* Furthermore, it is very evident that water is a very important factor in the living cell. We fully appreciate that water is absolutely necessary for life, growth and reproduction, but we do not fully understand the significance of water in the living plant.

Necessity of Water.—Water is necessary for all the life functions of the plant. Therefore, the water supply and its distribution throughout the year determines in great measure the kinds and number of plants found in different localities. In fact, water is one of the most important environmental factors in plant growth, and plant distribution over the earth. A study of the distribution of plants over the earth will show that water is fully as important as, possibly more important than, temperature and soil qualities. The great movements of the human race have been far more dependent on water for the production of their food and other necessities of life, for use in their various manufacturing industries and for transportation than on any other factor. The movements of mankind throughout all time have depended primarily on the amount and distribution of water. This is especially noticeable in a study of the settlement of America. The lines of migration have been primarily along the waterways and the success of settlements has been dependent more on water than on any other natural factor. Many thousands of acres of excellent land in our great West are not and cannot be used because of the lack of water.

Water as a Food.—Water is frequently referred to as a plant food. It is not a true food, but a crude or raw food that is absolutely necessary for the existence of life. It is the most abundant compound found in the plant. It is used not only in the manufacture of true foods, such as starch and sugar (see page 195), but it also acts as a solvent in which the mineral salts are dissolved before being absorbed by the plant.

Location of Plant with Reference to Water.—The great importance of water in the life and growth of the plant makes it necessary that the plant must be so located as to secure the water to the best advantage. Some plants, such as the pond weeds and Algæ, live more or less completely submerged in the water and may be either free floating or attached; other plants are anchored in the soil and are either floating (pond lilies) or erect (cattails); other plants live in swamps or wet soil, while the so-called dry land plants live in soil which must contain some water in order to support living plants. Therefore, it will be readily seen that the character of the vegetation in any locality, large or small, will depend largely upon the amount and distribution of the water supply. Although water is necessary for plant growth, an excess of water is injurious to many of our land plants. This is very evident in young corn during a period of excessive rainfall. It is largely due to the fact that the excess of water in the soil prevents the proper aeration of the root system (page 219).

Methods of Absorption.—Some of the lower forms of plants, especially the Algæ, take in water through any part of their surface, but the higher plants, including our agricultural crop plants, take in practically all of their water through their root systems. This is very evident when we take into consideration the character of the epidermal structures of the various parts of the plant which we have studied in the preceding chapters. For the present we will consider those plants only that live with their roots in the soil and secure their water from that source.

Character of the Soil.—In speaking of the soil, we usually refer to the layer of loose material covering the surface of the earth, which in most places is only a few inches in depth. It is very complex, both structurally and chemically, and varies greatly in different localities. In brief, it may be said to consist of powdered rock, containing a great deal of decayed plant and animal material, which is usually spoken of as humus, plus water and air. It also contains a great many microörganisms, some of which are very closely associated with plant growth (page 204).

It will be readily seen that the physical character or structure of the soil depends on the kind and fineness or coarseness of the powdered rock; that its chemical character depends on the kind of rock and amount of humus; that the amount of water in the soil depends not only on the amount of rainfall but also on the structure of the soil and amount of humus it contains; that the amount of air in the soil also depends on the structure and the humus. The rock is ground into powder by the action of water, frost and other natural factors, and the mechanical forces exerted by growing plants, the burrowing of small animals and the action of acids formed by the decaying of organic materials. This powder is carried by the action of wind, water and other natural agencies and mixed with powder from other localities. Therefore, a soil is frequently a mixture of materials of different kinds and from different sources, and varies in accordance with their origin and their physical and chemical properties. A very fine soil will retain a much higher percentage of water than a coarse soil. A soil with a high humus content will also retain a much higher percentage of water than a soil with a low humus content. Therefore, it will be readily seen that the water-holding power of coarse sand is low as compared with a fine sand, that clay and loam have a higher power of water retention than sand and that humus has a higher power of water retention than clay or loam.

The Rooting Habits of Plants.—Plants differ very materially in their rooting habits. Some plants send their roots deep into the soil, while others spread their roots out near the surface. Although the spreading and distribution of the roots in the soil is characteristic of the species of plant under consideration, it is influenced and modified to some extent by the character of the soil and the water supply and by their need for air (page 225). There is always a definite relationship between the top and the root system of the plant. In transplanting it is usually necessary to injure or destroy a part of the root system, and for this reason the growers of many crops, especially trees, prune the tops when transplanting, so that the root system will be proportionately as large or larger than the top. In due process of growth the plant will reëstablish the equilibrium between the top and the root system. The extent of the root systems of plants is surprising to those who have not given it some consideration. When we pull a plant from the soil many of the roots, especially the smaller ones, are torn off and we see but a very small part of the system. In the resetting of potted plants, the extent of the root system is revealed to much better advantage. The roots of our cultivated grains, such as corn, wheat and oats, grow to a depth of three to four and a half feet. A potato plant may, under favorable conditions, spread its roots through the greater part of a cubic yard of soil. The root system of a single wheat plant is said to aggregate more than 600 yards and that of a single pumpkin plant more than fifteen miles. Although these figures may appear to be exaggerated and may be exceptional, those who have made a study of the root systems of plants know that these organs are much more extensive than they are supposed to be by those who have not studied them. Some trees send their roots deep into the soil, while others spread them near the surface for long distances. The fact that our trees are able to withstand storms is sufficient evidence that they are firmly anchored by a wonderful root system. The method for measuring the root system of plants was developed by Rotmistrow of Russia and consists in growing plants in sunken boxes filled with soil. These boxes are one inch wide, twenty to forty inches long and twenty to forty inches deep. When the plants are mature, the boxes can be removed, opened and the soil washed from the roots with a minimum of injury. Although this method is open to objection it gives fairly accurate records.

Unavailable Water.—The plant cannot use all the water from the soil. Under ordinary conditions every particle of soil is surrounded by a film of water known as *hygroscopic water.* When the soil contains only the hygroscopic water it is said to be "air-dry." In general, it may be said that the plant cannot take water from the soil unless the amount of water exceeds three times the hygroscopic water. The water of the soil, which is in excess of the hygroscopic water, is usually known as *capillary water.* When the water content of the soil drops below three times the hygroscopic water, the plant wilts as a result of the withdrawal of the water in its tissues into the surrounding soil. In our ordinary, sandy, loam farm soils from 5 to 12 per cent. of the water is unavailable for most of our crop plants, but in the coarse sandy soils it may be reduced to 1 per cent. The amount of unavailable water varies greatly in different types of soil, as shown in the table:

	Hygroscopic Water	Unavailable Water
Coarse sand	0.42	1.5
Ordinary garden soil	1.68	4.6
Sandy loam	2.40	7.8
Peat soil	20.60	49.7

The amount of unavailable water also varies with the type of plant, when grown in the same soil, as shown in the following table:

Plant	Unavailable Water
Morning-glory	3.0
Cabbage	5.8
Corn	5.9
Sugar beet	5.9
Oats	6.2
Asparagus	7.0
Lettuce	8.5
Cucumber	10.8

Water Movements in the Soil.—The amount of water in our agricultural soil varies from season to season and from day to day. Immediately following a heavy rain the ordinary agricultural soil is saturated and contains more water than is necessary or can be used by the growing plant. In fact, the amount of water may be so great as to be injurious to the growth of the plants which ordinarily grow in that soil. This excess of water sinks into the deeper layers of the earth or evaporates into the air. During a period of reduced rainfall the evaporation of water from the soil and the absorption of water by the plant may reduce the water to a point below that necessary for the growth of the plant. However, these processes are accompanied by a movement of the water, due to the force of capillarity, from the lower layers of soil towards the upper or surface layers. Therefore, the plant is continually receiving a supply of water from below. During periods of drouth this supply is not sufficient for the normal growth and development of the plant.

Relation of the Root-hairs to the Soil and Water.—The structure of the roots is such that they do not take water directly. This function is performed by the root-hairs which are borne in a definite zone just back of the growing tip. They exist for a short time only and then disintegrate; new ones being formed as the root increases in length (page 65). The root-hairs are interwoven among the soil particles. They vary in number with the growth of the plant and the amount of available water. The actively growing plants need a large amount of water and must have the necessary number of root-hairs to secure this water supply. The soil water contains in solution many minerals which are necessary for the growth of the plant, some which are unnecessary, and, sometimes, some which are injurious (see Chapter XVII).

The movement of the dissolved minerals into the root hairs and thence into the roots depends primarily on the selective character of the permeable membrane, the density of the solution in the root-hair and the density of the soil solution. The amount of mineral salts entering the plant does not depend on the amount of water absorbed.

Imbibition.—The power to take up water is not restricted to living organisms. Blocks of dead wood will absorb water by imbibition, which is the power to take in and hold water by capillarity or surface tension. Blocks of dry wood which have taken up water by imbibition tend to swell or increase in bulk. This is an important factor in plant growth, for it must be remembered that not all parts of the living plants are necessarily alive. The heart wood of the living tree is composed of dead cells through which a great deal of water is passing by means of imbibition. The coats of seeds are composed of dead cells which imbibe the water very readily.

Diffusion.—This is the gradual movement or separation of the molecules of a gas or liquid (or in some cases of a solid) to a condition of less concentration. When two gases or liquids are in contact with each other there is a tendency to form a mixture of equal density throughout. This occurs even though the lighter of the two may be uppermost. It may be readily demonstrated by placing a crystal of some readily soluble colored material in a glass of water. The color will gradually diffuse throughout the liquid independent of the convection currents. This is equally true of any of the soluble materials, although there may be no color by which the movement may be observed.

The soil water contains many different salts in solution which become thoroughly mixed as a result of diffusion and other movements. The atmospheric gases become thoroughly mixed as a result of the wind currents, but there is also a continuous exchange of gases through the stomata which is due to diffusion (see pages 172 and 193).

Osmosis.—Osmosis is a purely physical process. When two solutions of different density are separated by a membrane which is permeable to the solvent and not to the solute (*i.e.*, semi-permeable membrane), there is always a movement of solvent molecules from the less dense to the denser solution. Such movement continues until the equilibrium is established. If the membrane is permeable to both the solvent and the dissolved substance, there is always movement of both water molecules and solute molecules through the membrane. But if the membrane is semi-permeable the solvent only is involved. Plant membranes are usually permeable to some solutes and impermeable to others. If in an open container the denser solution will increase in volume and if in a closed container it will exert a very strong pressure (see Turgor, page 165).

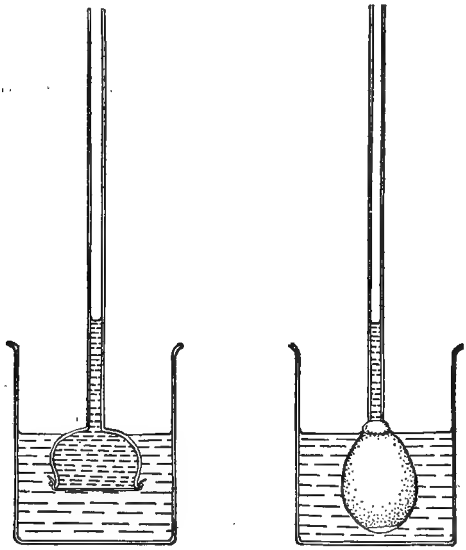

FIG. 96.—Apparatus for demonstrating osmosis; thistle tube on left and egg on right.

Demonstration of Osmotic Pressure.—This phenomenon is very easily demonstrated by soaking a semi-permeable membrane, such as an animal bladder or parchment, in water and tying it over the large end of a thistle tube by means of a waxed thread. The bulb part of the thistle tube is filled with a thick sugar solution and is then placed in a glass jar of distilled water so that the two liquids will be at the same level. The liquid in the thistle tube will rise to considerable height due to the passage of water through the membrane (Fig. 96).

Osmosis and Diffusion in the Living Plant.—In the living plant the root hair is the extension of a single epidermal cell. It contains protoplasm and cell sap which are denser solutions than the surrounding soil water. The outer surface of the cytoplasm is the plasmatic membrane. Therefore, there is a movement of the water by osmosis; from the soil, through the plasmatic membrane, into the cell. This will naturally tend to reduce the density of the cell contents and to establish an equilibrium between the cell sap and the soil water. But it will make the contents of the root-hair less dense than the contents of the adjoining cells in the root and destroy the equilibrium. Therefore, there will be an osmotic movement from the root-hair to the adjoining cells and in fact between practically all the inner living cells of the plant. However, the movements from cell to cell will be due not only to osmosis but also to diffusion and imbibition and possibly other physical laws.

The Cell Membranes.—The cell wall is a membrane through which water and dissolved materials pass very readily. It appears to have very little, if any, selective power and may be considered as permeable to most and probably to all liquid substances with which it ordinarily comes in contact in nature. Of course, this statement is not true of the epidermal cells which have been cutinized or suberized, but it does apply to practically all other cells in the plant body.

The cytoplasmic layer which lies next to the cell wall and to which we have previously referred as the plasmatic membrane does possess selective power. In fact, the life and growth of the plant depends on this selective power of the protoplasm. Its power and behavior may be summarized somewhat as follows: (*a*) it permits the entrance of necessary food-making materials; (*b*) it permits the entrance of some substances which are not necessary but may not be injurious; (*c*) it sometimes prevents the entrance of injurious compounds; (*d*) it prevents the outward diffusion and loss of food-making materials.

When the cell dies, the cytoplasmic layer or membrane loses its osmotic power, becomes permeable and permits all substances to pass through it in either direction. Therefore, coloring materials, sugars and other substances will not pass out of the living cell into the surrounding liquid but will very readily pass out of the dead cell. This is very evident in beets, which retain their coloring when alive, but give it out very readily after the cells are killed.

Chemical changes are continually taking place within the living cells and these changes are not necessarily the same in all parts of the plant. In fact, they are quite different in the different parts of the plant, especially in the different parts of the higher plants, in which the differentiation of cells into tissues is most complex. These changes are very evident when we take into consideration that only certain parts of the plant contain chlorophyll, and that only certain parts of the plant are used for food. These differences in the chemical character of the contents of the cells results in a loss of osmotic equilibrium and very naturally result in an osmotic interchange between the cells. Therefore, there must be a constant movement of liquids and an interchange of cell contents through the greater part of the plant during the growing season. The character of these membranes and the behavior of the cell contents present may complex phenomena which has not as yet been fully explained by scientists.

Turgor.—The movement of the water into the cell results in forcing the protoplasm against the cell wall, which, being more or less elastic, becomes distended. This is very noticeable on the free or exposed surfaces of the cells of such plants as the algæ, but less noticeable where the cells are in mass and the pressure of each is counteracted by the pressure of its neighbors. When the cells are overfilled with water and the walls distended, they are said to be *turgid.* The rigidity of the leaves and fleshy parts of the plants is due to the turgor of the cells. When the cells lose their turgidity the parts become flaccid and are said to be wilted. This accounts for the wilting of the foliage and for the shriveling of stored fruits, tubers and roots. If we study a wide range of plants we find a great variation in the turgidity of the cells. In our ordinary cultivated plants turgor in the epidermal and parenchyma cells is equivalent to that of a 7 per cent. sugar solution or about 4.5 atmospheres. It is much higher in some plants.

Hydrostatic Rigidity.—When the plant is in an active condition of growth, the cells are well supplied with water and the walls are distended; *i.e.,* turgid. This is well illustrated in fleshy plants and in the fleshy parts of woody plants, which are firm and erect because of the turgidity of the individual cells of which they are composed Even the most delicate plants are capable of sustaining relatively heavy loads when the cells are distended with water. This condition is known as *hydrostatic rigidity.* When the water content is lowered so that the cells are no longer distended the plants are wilted.

Plasmolysis and Wilting.—Plasmolysis is the opposite of turgor. If the soil solution surrounding the root-hairs is of a greater density than the sap within the cells, there will be an outward movement of the liquid within the cell (*exosmosis*), and the protoplasm will contract and withdraw from the cell wall (Fig. 97). The plasmolysis of the individual cells results in the wilting of the plant. However, wilting may be due to other causes, such as the loss of water by transpiration through the foliage.

Osmosis and Nutrient Salts.—The movement of water into and through the plant also involves the movement of the various salts which are dissolved in the water. The plasmatic membrane of the plant cell is permeable not only to the nutrient salts but also to many other substances, some of which may be neutral and others injurious. However, it is impenetrable to many substances and is therefore somewhat selective in its functions. Some materials tend to accumulate in the cells in considerable abundance, although they may be of no value to the plant. Methylene blue in water at the rate of 1 part in 100,000 is not visible, but certain plants growing in the water will collect this material in appreciable amounts. Iodine is present in sea water at a dilution of about .000001 per cent., but certain sea algæ will accumulate it in such quantities that it can be recovered on a commercial basis.

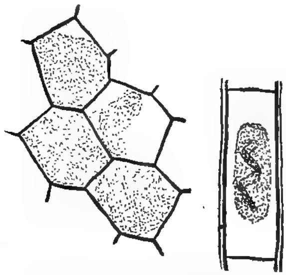

FIG. 97.—Three of the cells on the left are normal and one plasmolyzed; the cell of *Spirogyra* on the right is plasmolyzed.

Sap and Root Pressure.—Water moves into the root system and up through the stem of the plant with considerable force. This becomes very evident when plants are pruned early in the spring and is referred to as bleeding. This phenomenon is known as sap and root pressure. It is very evident that the various factors concerned with the absorption and movement of water in the plant, especially osmosis and turgor are important factors in sap and root pressure.

Plants should be pruned during the early fall or winter while dormant, or late in summer after they have passed the period of most active spring growth so as to prevent bleeding. Maple sugar is made very early in the spring when bleeding is greatest and the sugar content of the sap at its highest.

The Effects of Plants on Soil.—From a study of the foregoing it will be readily seen that growing plants are continually taking water from the soil and we will learn later that this water is given off by the foliage of the plant through the process of transpiration (Chapter XIV). Therefore, the plants are gradually reducing the water supply of the soil, which must be replenished by rainfall or other natural agencies. But this is only one of many influences which the plants exert on the soil. Plants also take up materials (Chapter XVII), which in a state of nature may be returned to the soil in the same or in different compounds, when the plants decay; or in the manure from animals, which have fed on the plants, or by decaying animals. The farmer removes a great deal of plant materials in harvesting his crops and this also brings about important changes resulting in a soil of reduced fertility. Plant roots are said to give off carbon dioxide and other compounds which no doubt react on the compounds already in the soil. The relative importance of this action on growing plants is not well understood. However, it appears that the carbon dioxide unites with the water, forming carbonic acid, which dissolves certain soil minerals, thus making them available for the growing plants. It is also claimed by some students that the roots give off enzymes which oxidize poisonous soil compounds and render them harmless. Decaying plant material is recognized as exerting a most important influence on the soil; the humus of the soil, which is so important in plant growth, is recognized as coming from the decay of organic materials. However, it is also well known that both living and decaying plants produce compounds which are injurious to plant growth; therefore, it is frequently necessary to give the soil mechanical and chemical treatments, or to allow it to remain idle for a time, or to practice the rotation of crops in order to maintain a maximum production.

LABORATORY EXERCISES.

Exercise 1. Chop 10, 50 or 100 grams of lettuce or cabbage leaves. Weigh carefully. Dry thoroughly in an oven at a temperature of about 100 degrees C. Weigh and compute loss in water. Repeat this experiment, using twigs, fruits and seeds of various kinds.

Exercise 2. Grow several plants in unperforated glass or porcelain containers filled with soil of the same kind. When well started, insert the stem of a funnel into the soil and cover the surface of the soil with a soft wax composed of a mixture of paraffin and vaseline. Water the plants through the funnels from day to day, using different amounts of water for each plant. Note the effect on growth.

Exercise 3. Note plants growing in the open. What plants grow in the water, in swamps and on dry land?

Exercise 4. Review your studies of the root-hair (Chapter IV).

Exercise 5. Place a few root-hairs on a slide in methylene blue and observe under the microscope. Note the penetration of the color.

Exercise 6. Examine and compare two or three types of soil under the microscope.

Exercise 7. Fill glass tubes about two feet in length and about one-half inch in diameter with soil of various types, and stand in water. Note the rise of the water.

Exercise 8. Dry definite amounts of two or three types of soil thoroughly; add definite amounts of water and expose in open vessels for a few hours. Weigh and compute the relative water losses.

Exercise 9. Pull seedlings that have been grown in loose soil and examine the root-hairs under the microscope. Note the relationship to the soil particles.

Exercise 10. Grow seedlings of the same kind in soil of the same type in two four-inch pots. When the seedlings have several leaves, quit watering one lot. When wilting begins, determine percentage of water in the soil.

Exercise 11. Place living shoots of Elodea or similar water plants or living algæ in about 1000 times their volume of .01 per cent. solution of methylene blue for about 24 hours. Examine for color. When the color is noticeable, plasmolyze the cells with potassium nitrate solution.

Exercise 12. Cut cubes of soft, dry wood, measure carefully and soak in water for several days. Measure again. The water should be changed every day.

Exercise 13. Fill a thin test tube with dry peas. Tie a cloth over the mouth of the tube and place in water for 24 hours. Note the result.

Exercise 14. Put 100 to 200 grams or more of well powdered starch that has been dried at 105 degrees C. in each of two glasses and 100 to 200 c.c. of water in a third glass. Put tested, uniform thermometers in the glasses and set in a water bath at room temperature until the thermometers register the same. Pour the water into one of the glasses with starch and mix thoroughly. Note the rise in temperature as compared with the others.

Exercise 15. Fill a test tube about two-thirds full of thick, colored molasses, using care not to smear the sides. Very carefully and gently add an equal amount of water. Note gradual mixing due to diffusion from day to day.

Exercise 16. Place a large crystal of potassium ferrocyanide or chromic acid in a glass of water. Note the gradual diffusion.

Exercise 17. Place a drop of copper sulphate in a 5 per cent. solution of potassium ferrocyanide and note the formation of the semi-permeable precipitation membrane.

Exercise 18. Make 250 c.c. of .5 gram molecular (M) solutions of potassium nitrate and sodium chloride. Using these as stock solutions, make .10, .20, .30, and .40 molecular (M) solutions of each in quantities of about 25 c.c. Select lettuce, radish or mustard seedlings of about the same size and suspend one in each solution. Note the time of wilting of each. Examine the root-hairs under the microscope for plasmolysis.

Exercise 19. Use the same solutions as in 18. Split the flower stalks of the dandelion into four parts and dip into water. When the spirals are well formed, cut into distinct rings and place one ring in each solution and note the result. Further curling indicates absorption of water, while extension indicates loss of water, *i.e.*, plasmolysis.

Exercise 20. Fasten a piece of soaked pig's bladder over the bulb of a thistle tube. Fill the bulb with molasses and suspend in distilled water so that the two liquids are on the same level. Observe from time to time and note the result.

Exercise 21. Cut two 1 cm. cubes of red beet. Put one in water at a temperature of 70 degrees C. for 10 minutes. Then put both in lukewarm water and note effect on the color. Explain.

Exercise 22. Repeat the last exercise, but freeze one cube instead of heating.

Exercise 23. Turgor. Hollow out three beets or carrots or turnips or potatoes. Fill one with sugar and one with salt. Put all three in a closed chamber and keep for 24 hours. What is the effect?

Exercise 24. Wilting. Prepare a 1, 5, 10 per cent. solution of sodium chloride. Fill three jars and also one other jar with distilled water. Place seedlings in each and note time required for wilting.

Exercise 25. Cut a fresh section of a beet and keep in alcohol for two minutes. Mount in water and note the effect on the color.

Exercise 26. Cut thin slices of a fresh fleshy root, such as turnip or carrot. Keep in salt solution for one hour and note the effect. Transfer to distilled water for one hour and note the effect. Explain.

Exercise 27. Cut a section of a fresh garden beet and examine under the microscope. Note the contents of the cells.

Add a few drops of salt solution and note the effect.

Wash and remount in distilled water and note the effect.

CHAPTER XIV

TRANSPIRATION

Transpiration.—We have already learned that water is taken in through the roots of the plants and that there is a movement of the materials dissolved in it throughout the greater part of the plant. Some of this water is used in the formation of carbohydrates (see page 195), but most of it is given off through the foliage and other green parts of the plant. *Transpiration* refers to the giving off of water by the plant. The water is given off from the leaves and other green parts of the plant and to some extent from other parts of the plant as a vapor. In some plants this process is very rapid, while in others it is relatively slow. The amount of water in the plant at any time is not an index of the amount which passes through the plant. Transpiration must not be confused with respiration, which will be referred to later (page 221). The transpiration of water by the plant was originally supposed to be the same or similar to the exhalation of vapor from the lungs of animals. But later studies have shown that these processes are not the same, and it is better to consider the transpiration of water from the plant as a process in which the plant is passive. Of course, we do not know what conclusions further study may lead to, but for the present we will describe it as a mechanical or physical process very similar to evaporation but differing from it in that it is modified or controlled to some extent by the structure of the plant and the living protoplasm within the cells.

Transpiration varies in different species of plants, in different parts of the same plant and during different periods of the day and night and different seasons of the year. It is usually very low in desert plants and high in land plants which have an abundant water supply; low at low temperature and high at high temperature; low at night and high during the day. It has been estimated that it is necessary on the average for 300 pounds of water to pass through a plant in the production of one pound of dry material. Of course, it is higher for some plants and lower for others, being about 272 pounds in the case of corn and about 557 pounds in the case of oats, depending upon the aerial and sub-aerial environment of the plants. Leaves are the organs of greatest importance in transpiration, but this process also takes place through stems, flowers, fruits, seeds and practically all parts exposed to the air. The transpiration of water from stored fruits and vegetables results in their wilting.

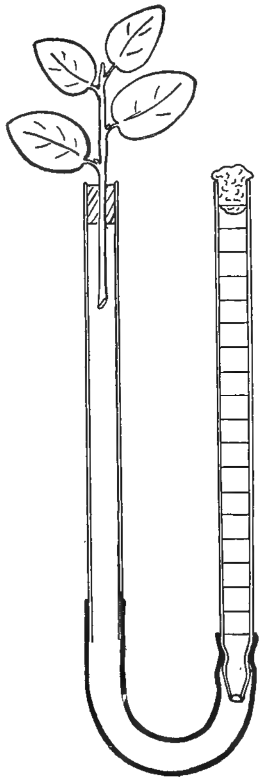

FIG. 98.—Potometer used in demonstrating transpiration.

Demonstration of Transpiration.—This process may be demonstrated by wrapping a potted plant with a rubber cloth so as to prevent evaporation from the surface of the pot and soil. Weigh carefully and place under a bell jar. In the course of a few hours moisture will be observed on the inner surface of the bell jar. Weigh again and subtract from the first weight and thus determine the amount of water that has been transpired through the exposed parts of the plant. This process may also be demonstrated by the use of the potometer, but it should be remembered that an injured plant is abnormal and therefore its activity is not altogether comparable to the uninjured plant (Figs. 98 and 99).

A very simple potometer may be made by using two glass tubes, one of which is graduated. These two tubes are held in an upright position and attached at their lower ends by a rubber tube. They are filled with water and a freshly cut leafy shoot fastened in the upper end of the ungraduated tube by means of a perforated cork and sealed with wax or adhesive tape, so that the water cannot escape except through the shoot. The fall of the water in the graduated tube can be readily measured.

In nature, excessive transpiration results in wilting and sometimes in the death of the plant. Cut flowers wilt because they do not have a water supply, although transpiration continues. If kept with the cut ends in water, they continue to absorb water and maintain their rigidity. Apple, potatoes and fleshy roots, although protected by heavy epidermal structures, continue to transpire and slowly wilt when kept in storage.

The Plant Mechanism Permitting Transpiration.—We have already learned that the structure of most leaves consists of an upper and a lower epidermis of one or occasionally more layers of cells in which the exposed surfaces are protected by a *cuticle*; a layer of palisade cells next to the upper surface; a more or less loose mass of mesophyll cells between the palisade and the lower epidermis, and many stomata which are usually most abundant on the lower surface. The stomata open into more or less extensive passages or intercellular spaces among the mesophyll cells (Figs. 59 and 60). The mesophyll cells in contact with the spaces are always moist, due to moisture forced out from the cells. The atmosphere has free passage through the stomata and into the intercellular spaces. The air in the intercellular spaces is gradually taking up moisture which passes to the outside by diffusion. There is also an exchange of gases which will be considered later (see page 195). Much of the

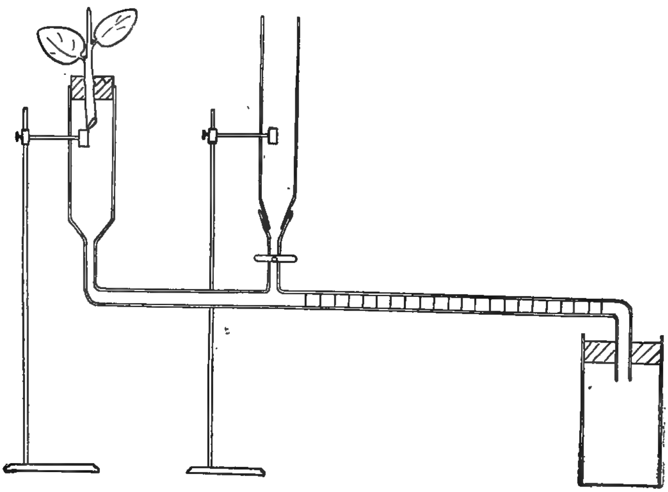

FIG. 99.—Potometer used in demonstrating transpiration.

transpiration takes place through the stomata, but it may also take place through the entire surface of very young leaves and to some extent through other parts of the plant. The number of the stomata varies in the different species of plants, and in plants of the same species when grown under different conditions of soil moisture, air humidity, light, temperature and other factors. They are usually most abundant on the under surface of the leaves, as shown in the following tables:

Leaves with no Stomata on the Upper Surfaces.

Plant	Stomata per sq. mm. on lower surface of leaves
Olive (Olea europœa)	625
Black walnut (Juglans nigra)	461
Norway maple (Acer pseudoplatanus)	400
Lilac (Syringa vulgaris)	330
Red currant (Ribes aureum)	145
Rubber plant (Ficus elastica)	145
Nasturtium (Tropæolum majus)	130
Lily (Lilium bulbiferum)	62

Leaves with few Stomata on the Upper Surfaces.

Plant	Lower surface	Upper surface
Bean (Phaseolus vulgaris)	281	40
Poplar (Populus dilatata)	270	55
Pumpkin (Cucurbita pepo)	269	28
Tomato (Lycopersicum esculentum)	130	12
Bitter sweet (Solanum dulcamara)	263	60

Leaves with Stomata Nearly Equal on the Two Surfaces.

Sunflower (Helianthus annuus)	325	175
Cabbage (Brassica oleracea)	301	219
Garden pea (Pisum sativum)	216	101
Corn (Zea mais)	158	94
Oats (Avena sativa)	23	25
	27	48

Leaves with More Stomata on Upper than on Lower Surfaces.

	Lower surface	Upper surface
Wheat (Triticum sativum)	14	33
Water lily (Nymphæa alba)	0	460
Water birch (Betula alba)	0	237
Barberry (Berberis vulgaris)	0	229
Cottonwood (Populus deltoides)	89	131

Stomatal Movements.—The stomata, as previously stated, open into the irregular intercellular spaces or chambers in the mesophyll. Therefore, many of the mesophyll cells are brought into direct contact with the atmospheric gases which pass by diffusion through the stomata. The mesophyll cells have thin walls, which are not cutinized and which permit the free passage of both liquids and gases.

Stomatal Production and Movement.—The number of stomata is not constant in plants of the same species but varies with the moisture content of the air and soil, the light, temperature and other factors. The guard cells undergo certain movements which result in the opening and closing of the opening. These movements of the guard cells are due to turgor and are not directly related to the moisture condition of the air. They are usually open when the plant is receiving a sufficient amount of moisture and are usually closed when the moisture is insufficient, but they do not open and close in anticipation of conditions favorable or unfavorable to the plant. They are also influenced to some extent by the intensity of the light.

Conditions Influencing Transpiration.—Humidity, temperature, light, wind velocity and leaf modifications are the most important factors influencing transpiration.

(*a*) Transpiration will take place unless the humidity of the air is equal to or greater than the humidity of the air in the intercellular spaces of the plant. In general, it may be said that the transpiration increases in proportion to the dryness of the surrounding atmosphere.

(*b*) Transpiration usually increases with the rise of the temperature of the air, provided other conditions remain the same.

(*c*) Transpiration usually increases with the increase in the intensity of light. This is due to the fact that a part of the energy of sunlight absorbed by the leaf is transformed to heat, which gives the leaf a temperature that may occasionally be as much as 10 or 15 degrees C. higher than the surrounding air.

(*d*) Transpiration is increased by the movement of the wind. It is estimated that wind moving at a velocity of 30 miles per hour will evaporate water about six times faster than calm air.

(*e*) Transpiration is influenced by various leaf modifications. These modifications vary with the factors which we have discussed above. An examination of plants growing under the various conditions presents some very interesting facts, some of which will be given very briefly:

(1) The corn leaves roll during a drouth.

(2) The cactus, aloes and many other plants growing under dry conditions have reduced surfaces.

(3) The yuccas and carnations have the stomata at the bottom of the epidermal pits.

(4) The pines and many desert plants have very thick cuticles.

(5) The cabbage leaves have a waxy covering.

(6) The mullein and many other plants have numerous hairs which check transpiration.

(7) Many plants, especially those growing in arid regions, have special devices for the storage of water.

Advantages of Transpiration.—(1) Transpiration is one of the factors influencing the movement of water through the plant. The more rapid the transpiration, the greater the movements of water. (2) Transpiration decreases with the lowering of the atmospheric temperature in the same manner as ordinary evaporation from an exposed surface of water. Under normal conditions there is a movement of water from the organs of absorption (usually the roots), to other parts of the plant. This movement of water is not well understood but is no doubt due to many factors, of which the most important are: (1) the movement from living cell to living cell by the laws of osmosis, (2) the movement from cell to cell by the laws of diffusion, and (3) the movement through the fibrous cells, more especially the tracheary tubes, by the laws of capillarity. However, the combination of these forces does not appear fully to explain the movement of the water from the roots to the tops of tall trees.

When the water reaches the leaves it is transmitted to the mesophyll and palisade cells. Some of it is used in the formation of carbohydrates (see page 195) and possibly other compounds, but by far the greater part passes through the cell walls into the intercellular spaces and out through the stomata. Since the amount of water in the leaf is being reduced by transpiration, there must be a continuous movement of water from the roots, up through the stems and into the leaves. Of course, this moving water carries the various compounds which are in solution in it. Transpiration is a continuous process, varying in accordance with the age of the organs, the part of the plant, the season of the year, the hour of the day or night, the humidity, the temperature and many other factors. One of the most important secondary effects is the lowering of the temperature of the plant, thereby preventing injury due to excessive heat.

Excessive Transpiration.—The results of excessive transpiration are pronounced and frequently the cause of heavy crop losses. It checks the growth and yield of many plants, especially corn; it prevents pollination in some plants and causes the falling of flowers and leaves and sometimes twigs in others. The falling of twigs, frequently referred to as self-pruning, is very common in many plants, especially the poplars. It reduces the leaf surface and lowers the transpiration. The leaves on these self-pruned twigs are usually green and apparently in a normal condition. Twigs and leaves that fall in this manner do not break off but grow off by the formation of a definite cleavage plane in the same manner that leaves fall in the autumn. The excessive transpiration is usually the result of hot, dry weather periods known as drouths. The drouth periods frequently extend over large areas and form one of the most common causes of crop failure in the Mississippi Valley States. We have already learned that excessive transpiration is controlled to some extent by the rolling of the leaves, the reduction of the transpiring surface, the modification of the stomata, the thickening of the cuticle, the formation of a waxy covering, the formation of trichomes, and the development of special devices for storage (see page 175).

Other Water Losses.—Although transpiration may be looked upon as the most important method by which the plant loses water, it is not the only one. The plant also loses water and compounds in solution by guttation, bleeding and secretion.

Guttation.—This term refers to the excretion of water from the modified stomata (frequently called water pores) along the edges of the leaves of many plants, especially the cabbage, canna and young corn. The water is given off in much greater abundance than through the ordinary stomata and is usually more prominent at night than during the day. The drops of water on the margins of the leaves are sometimes very noticeable during early morning hours and on plants grown in the greenhouse.

Bleeding is the giving off of sap from wounds. It is most common in the early spring. The maple-sugar makers make use of this phenomenon and tap the trees at just the right time to secure the maximum flow of sap. Trees should be pruned at such time as to avoid bleeding.

Secretion is a very common phenomenon, but is always by specialized cells which are frequently arranged to form definite glands. It is more common than guttation or bleeding, the variety of substances produced is much greater but the quantities lost by the plant are much smaller. Some of these secretions are very important in the life of the plant, but others are apparently of no use and are considered waste products. Among the most important of these secretions are the volatile oils, alkaloids and glucosides (see Chapter XI).

The glands vary in both structure and in the character of their secretions. The simplest form of gland is a single epidermal cell which may be on the same level or above or below the level of its neighbors; a more complicated type consists of a mass of cells in a group or a filament; or a group of cells lining a simple or complex cavity. The glands in the skin of the orange are very large and easily studied, but they are only one of the many types of glands to be found in plants. The chemistry of secretions is very imperfectly understood, but we know that some glands secrete water, others sugar, others salts, others water containing enzymes, others oil and still others the nectars. The nectaries of flowers are highly developed glands.

Water Transport.—Since the water is taken in through the roots of the plant and given out through the leaves and other green parts, it is evident that it must pass through the stems. With some few exceptions, we may say that the water of the plant is always associated with substances in solution. The movement of water in the living plant is very complex and as yet we have no entirely satisfactory explanation of this phenomenon. In general, it may be said to be due to osmosis, diffusion, capillarity, cohesion, transpiration and other factors.

There is no true circulation of water or other fluids in the plant comparable to the circulation of the blood in animals, but in general it may be said that the plant fluids follow more or less definite courses. The water passes upward through the xylem of the fibro-vascular bundles, carrying more or less soluble substances, more especially the mineral constituents. There is also a gradual downward movement of the soluble organic constituents through the protoplasmic contents of the sieve tubes and from them, by diffusion, into the actively growing cells.

In the lower land plants, such as the liverworts and mosses, the tissues are simple and the water travels for short distances and its movements can be explained by osmosis. But in the larger plants, in which the distances for transport are great, the tissues are correspondingly complex and highly differentiated and the transport much more difficult to explain.

Girdling.—Trees will live, after being girdled, for the remainder of the season, because the flow of water and dissolved food materials is unaffected by the girdled part, but will die during the winter, because the girdling prevents the downward flow of the protein materials which are normally stored in the roots for use the following spring. The girdling of a branch of a fruit tree or vine will prevent the downward flow of protein through the phloem and cause it to be diverted to the fruit, which becomes larger than normal. These fruits are said to be forced. The same result is frequently brought about by winter injury of trees at the surface of the ground; some of the cortex and phloem are killed, which results in a partial or complete girdling.

Other Losses.—But transpiration, guttation, bleeding, etc., do not explain all the losses by the growing plant. Gases are given off by the foliage and other green parts (see page 196). Carbon dioxide and other compounds are given off by the roots. Leaves and flowers, twigs, fruit and branches fall and the bark peels off slowly and is renewed from within (see page 52). The total of these losses is very great.

Most of our trees are deciduous; that is, they lose their leaves in the winter; but trees frequently lose both leaves and branches during periods of drouth. Of course, the cold weather of winter checks the work and growth of the plant and injures delicate structures, but the falling during periods of drouth reduces the leaf surface and thereby reduces the amount of transpiration. The falling of leaves and branches is not due to breaking off but due to the formation of definite layers of cell at the base of the petiole or branch (see page 102). This process is known as abscission. Evergreen trees shed their leaves gradually throughout the entire life of the trees. The changing of color of leaves at the approach of winter is not well understood but it is evidently due to chemical changes within the cells.

LABORATORY EXERCISES.

Exercise 1. Soak two pieces of filter paper in 5 per cent. or stronger solution of cobalt chloride. *Dry thoroughly.* Place an active leaf between them for a few minutes and then note the color. Pink indicates absorption of water. Which side of the leaf gives off most water?

Exercise 2. Take an active growing potted plant such as Geranium or Begonia. Water thoroughly, wrap in sheet rubber so as to cover both pot and soil and attach about the stem of the plant. Under these conditions no water can escape except through the plant. Weigh from time to time and record the loss.

Exercise 3. Use a Ganong potometer (Fig. 99), burette potometer (Fig. 98) or other satisfactory device and determine the amount of transpiration in a given time.

Exercise 4. Fill a bottle three-fourths full of water and close with a rubber stopper with two holes. Into one hole fit a leafy shoot, the lower end of which is cut obliquely and submerged. Into the other hole fit an L-shaped glass tube, but with end not submerged. Fasten a rubber tube onto the outer end. Make a partial vacuum by sucking the air out. Note the rise of bubbles from the lower end of the plant. Explain.

Repeat, using a stem in winter condition.

Exercise 5. Guttation. Put growing seedlings of cabbage, wheat, oats, corn or other plants under large bell jar. Note the drops of water on the tips of the leaves.

Exercise 6. Collect some of the guttation drops on a clean slide. Allow to dry and examine under the microscope. Does guttation water contain salts?

Exercise 7. Place freshly cut growing shoots in a solution of eosin. (The shoots should be cut under water.) Examine from time to time and note the rise of color. Cut thin sections and examine under the microscope. Through what part of the stem does the color rise?

CHAPTER XV

WATER REQUIREMENTS FOR PLANT GROWTH

Water Requirements of Plants.—It is very evident from the preceding studies that plant growth necessitates a large amount of water and that the water requirements vary greatly for different plants, for different parts of the same plants and for plants at different seasons of the year. It has been estimated that an average of about 300 pounds of water are necessary for the production of one pound of dry matter. This is an average and, of course, varies for different species of plants and for plants grown under different conditions. In the following table the figures represent the number of pounds of water used in the production of one pound of dry matter. The two columns represent the results of different workers.

Mustard	843	774
Barley	262	274
Oats	402	665
Buckwheat	664	371
Red clover	249	453
Pear	235	479
Potatoes	423	
Rye	377	
Wheat	225	359
Bean	214	262
Corn	233	

The variation in the figures in these two columns may be accounted for by the fact that the tests were made in different parts of the world and therefore the plants were subjected to different temperature, humidity, soil and other important environmental factors which would influence their growth.

Precipitation and Plant Growth.—It is very evident that plant growth depends in a great measure on the amount of rainfall, its distribution throughout the year, and the water-retaining character of the soil. Most of the water that falls on the earth runs off into the streams and thence into the lakes and seas and is lost so far as land plants are concerned; a considerable amount percolates through the soil and it is also lost for land plants; a considerable amount evaporates from the surface of the soil and is lost. Therefore, a comparatively small amount of the rainfall is really available for plant growth.

It is well known that the amount and distribution of rainfall varies greatly in different localities. A study of the precipitation map of the United States will demonstrate this point quite clearly. A study of the crop maps shows that our crop production coincides very closely with these rainfall areas (Figs. 100 and 101). The plants that require large amounts of water are restricted to the areas of greatest rainfall or to the areas where irrigation is practical. Of course, temperature and soil and other factors are important and will be taken up later. The lack of rainfall is overcome in some of the arid sections of the country by means of irrigation.

Ecological Classification and Crop Production.—The amount of available water is one of the most important controlling factors in plant growth; in fact, life and growth are absolutely impossible without water. However, the water requirements for different species of plants are quite different. Therefore, it is very natural that those species of plants which have practically the same water requirements will be found growing in the same locality; in fact, in very close association; although they may be very different in character and in appearance. On this basis, plants have been classified into three large

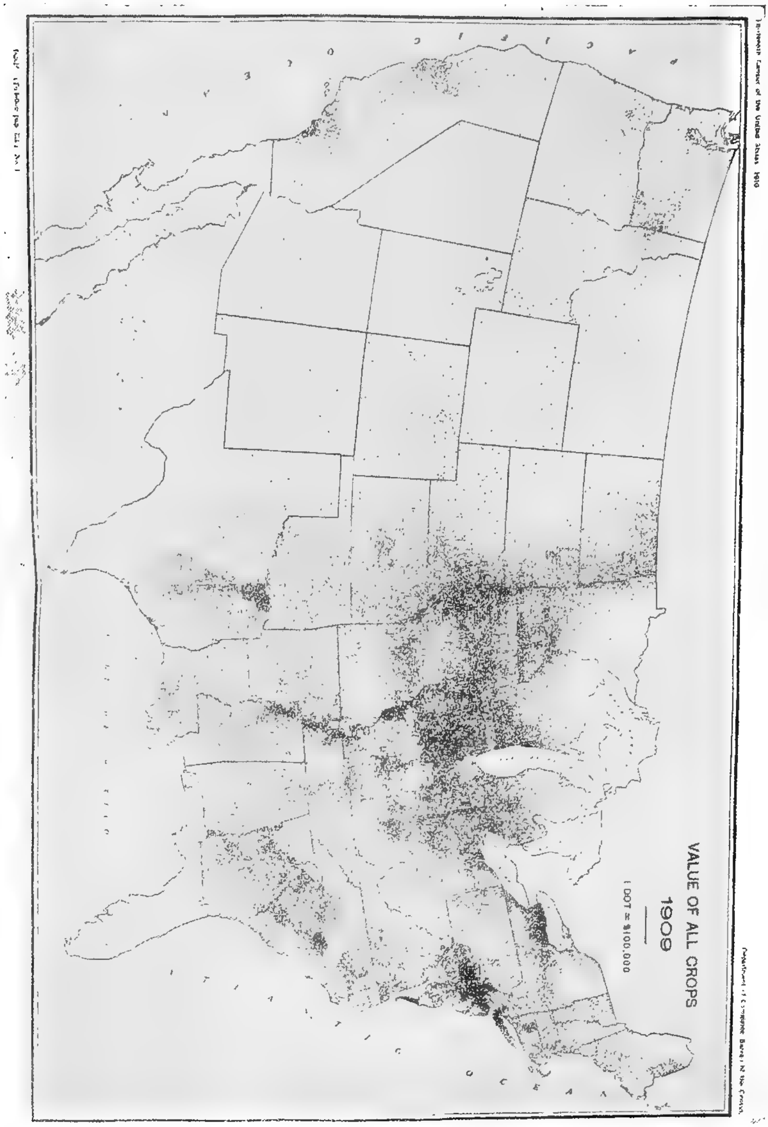

FIG. 100.—Map showing areas of greatest crop production in the United States.

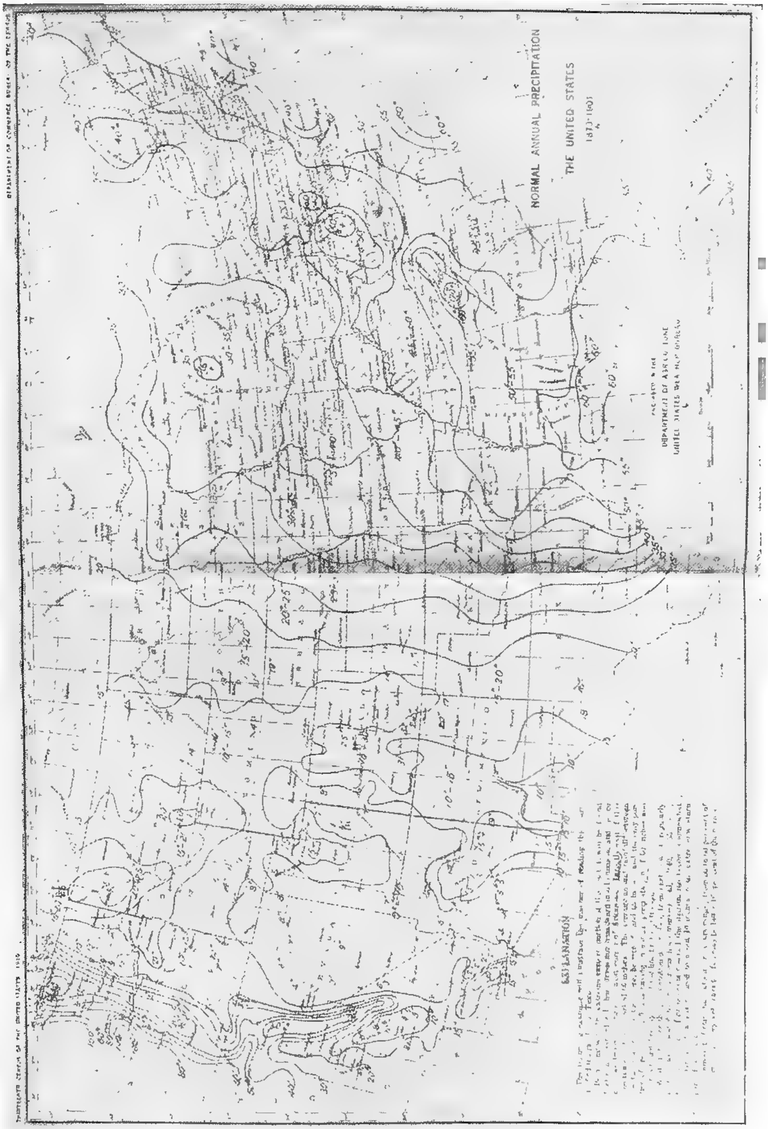

FIG. 101.—Map showing annual precipitation in the United States.

groups, each of which can be subdivided into smaller groups. They are called societies and are as follows:

Xerophytes.—This society includes those plants which require but very little water. The anatomical structures for retaining water, such as fleshy organs for storage of water, reduction of leaf surface, abundance of trichomes and sunken stomata, are very prominent in these plants. The most conspicuous subordinate division is the *desert and dry plain group,* which includes the cacti, sagebrush, yuccas and similar plants. Other important groups are the *xerophytic thickets* of the southwestern United States, which are frequently spoken of as the chaparrals; the *xerophytic forests,* composed of pines, spruces, firs and related plants, and the less prominent *rock societies,* consisting mostly of lichens and mosses. Many thousands of acres of most excellent agricultural land are now occupied by the xerophytic plants. In some parts of the world it is possible to reclaim this land by means of irrigation. Many thousands of acres within the boundaries of the United States have already been reclaimed.

Mesophytes.—This society includes those plants which require a medium amount of water and includes the great mass of land plants. The most prominent subdivisions are the *meadow* and *prairie* societies, which include numerous grasses and other herbaceous plants which are very generally associated with them; the *deciduous forests,* which include our common trees, such as the oaks, hickories, walnuts, elms, maples, beeches, chestnuts, cherry, catalpa, sycamore and poplars; the *mesophytic thickets,* which include our common shrubby plants, such as hazel, alders, willows, spice bush, viburnums and most berry bushes; and the *rain forests* of tropical countries which include the dense jungle growths. The great majority of our agricultural crop plants belong to the mesophytes.

Hydrophytes.—This society includes those plants which require a maximum amount of water; in fact, plants which live submerged in, or floating on, or standing in the water. They include species from all parts of the plant kingdom, from the lowest to the highest. The most prominent subdivisions are the *free swimming* societies, which include the free algæ and duck-

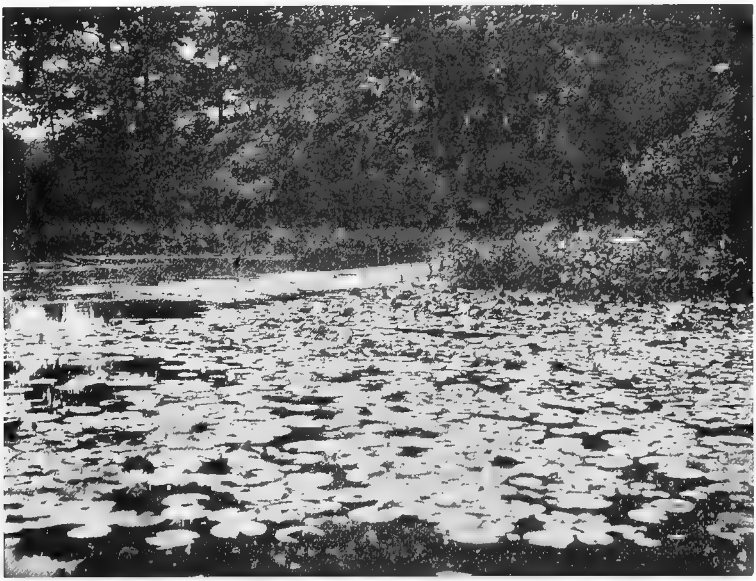

Fig. 102.—Zone formation of vegetation dependent upon depth of water.

weed; the *pond* societies, which include the pondweeds, water lilies, water ferns and the attached algæ; the *swamp* societies, which include the more or less erect plants which are partly submerged, such as the cattails, sedges and various reed plants. The swamp group may also include the sphagnum moss, many of the orchids, cranberries, alders, willows, birches, poplars, tamarack, hemlock and some of the pines. Rice and cranberries are the most important agricultural plants among the hydrophytes (Figs. 102 and 103).

Plants may also be grouped with reference to temperature, soil, fresh or salt water and many other environmental factors. In nature we always find the character of the plants dependent on a combination of factors which may be considered

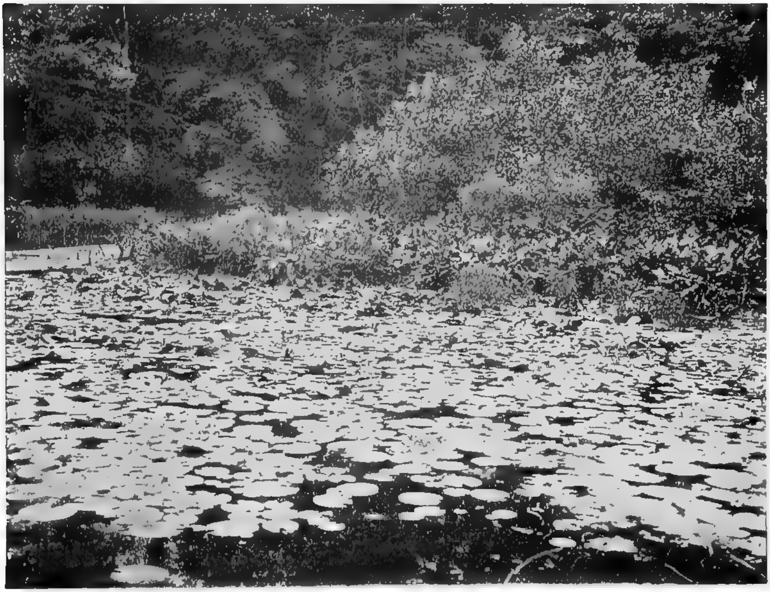

FIG. 103.—Zone formation of vegetation dependent upon depth of water.

as physiological. The study of the grouping of plants in nature and their relationship to their environment is usually known as Ecology.

It will be readily seen that plants which are widely separated so far as phylogenetic relationships are concerned, frequently grow under the same environmental conditions. This is especially noticeable among the hydrophytes, in which, as previously noted, we find the great range of plants from the lowest algæ to the most complex of the flowering plants.

A thorough knowledge of ecology is necessary for the study of plant distribution and for those who make a study of the introduction of important commercial plants from their native habitat to other parts of the world where they can be grown with profit. Many of our most important crops were originally restricted to very limited areas. Some governments employ agricultural experts to travel and study in other parts of the world for the purpose of securing new and valuable crop plants. The United States Government employs a corps of explorers who make explorations into the most remote parts of the world in search of valuable economic plants. Many of our valuable crop plants have been obtained by these explorers.

Plant Succession.—However, conditions do not remain the same and with the changing conditions we find changes in the character of the vegetation. Swamps, ponds and lakes are slowly filled up by the soil and debris that is washed into them, and this is followed by a change in the types of vegetation which is very evident. Sand dunes may move very frequently and destroy vegetation or may become more or less stationary by the slow action of the sand-binding plants. However, there are much greater changes which have required long periods of time; such as the changes in types of trees which make a forest area. Man has also brought about many changes by drainage of swamp areas, digging of irrigation canals and ditches, removal of forests and other activities which influence the character of the vegetation.

Plant Geography.—Many of the various types of plants dependent on the water supply can frequently be found within a very small area. But plants are also influenced by temperature, light, soil and many other factors. These factors are variable and in a state of nature work in combination. Therefore, the presence of any particular species of plant in any locality is dependent on all the environmental factors which influence its growth. The study of the distribution of plants over the surface of the earth is known as plant geography. It will be seen that plant geography depends on plant ecology, the latter being a study of the environmental factors influencing plant growth and the former a study of the distribution of plants as a result of the influence of environmental factors.

Crop Zones.—We frequently hear references to the crop zones or belts of the United States. Some of the most prominent are the cotton belt, the corn belt, the winter wheat belt, the spring wheat belt, the potato-growing districts, the rice-growing districts, etc. These areas are dependent entirely on the environmental factors just referred to. But there are many smaller areas which are just as well or better defined than the large areas. There are also the great arid and semi-arid districts of the far West and Southwest, much of which can never be irrigated. The agricultural development of a country depends largely on a knowledge of the factors involved in plant growth. A knowledge of these factors is also necessary in order that valuable plants can be introduced from other parts of the world and grown advantageously. Some crops will grow under a variety of conditions and will frequently vary in character in accordance with the conditions. The hard wheats are grown under semi-arid conditions, while the soft wheats are grown under conditions with a higher water supply.

LABORATORY EXERCISES.

The grouping of plants into societies can be observed in any locality. This chapter should be followed by a study of plants in the field.

CHAPTER XVI

RELATION OF CARBON DIOXIDE TO PLANT GROWTH

Source of Carbon.—This element exists in the soil in inorganic compounds, such as carbonate of lime, carbonate of magnesia, etc., but the plant cannot use the carbon in this form for the manufacture of organic compounds. The carbon for these functions is obtained from the air in the form of carbon dioxide. Under ordinary conditions the atmosphere contains from .028 to .03 per cent. of carbon dioxide. We have no reason to believe that this amount is materially changed from year to year, although it has probably undergone very decided changes during the long geological periods of the earth's history. The burning of fuel, the distintegration of rock carbonates of the soil, the breathing of animals and the decay of organic materials set free great quantities of carbon dioxide which becomes available for plant growth. The amount of CO_2 may be slightly greater in the vicinity of cities and near the ground, but the movements of the air currents tend to keep it very equally distributed. The presence of carbon in the plant can be very readily demonstrated by drying and burning the plant so as to form charcoal, which is pure carbon plus the small amount of mineral ash to which we have previously referred.

Composition of the Air.—The air contains approximately:

79 per cent. of nitrogen.
20 per cent. of oxygen.
00.03 per cent. carbon dioxide

The nitrogen of the air plays no direct part whatever in the growth of the plant (see page 203); both oxygen and carbon dioxide are taken up by the plant, but the carbon dioxide being about thirty times more soluble than the oxygen is taken up much more rapidly. Both of these gases are also given off by the plant, but the oxygen is given off in far greater abundance. Since the animal takes in oxygen and gives off carbon dioxide, it will be readily seen that plants and animals are mutually helpful to each other.

Absorption of Carbon Dioxide.—Gases of the atmosphere pass by diffusion in and out of the stomata (see page 172) and thus come in contact with the very delicate walls of the inner cells of the leaves and other green parts of the plants. These cell walls are always moist with imbibed water, Therefore, since we have a liquid on both sides of the cell walls we have the necessary conditions for liquid transfusion and for osmosis. More or less CO_2 is absorbed by the water on the outside of the cell wall which becomes carbonic acid. Oxygen from the atmosphere is also absorbed, but, as previously stated, the carbon dioxide is thirty times more soluble than oxygen and, therefore, is absorbed much more rapidly. More or less of this weak carbonic acid passes through the cell wall and thus into the cell sap, where it is acted upon by the sunlight and used in the formation of carbohydrates, as will be described later (see page 195).

The Cells, the Factories of the Plant.—We have already learned that the living cells contain protoplasm, which is necessary for the formation of all other plant products. We have also learned that certain of the plant cells contain chlorophyll which is necessary for the making of carbohydrates. If the plant did not contain chlorophyll, it could not manufacture carbohydrates and life would be impossible. Therefore, chlorophyll is one of the most important substances in nature. The sunlight is the form of *energy* by which the plant is able to manufacture carbohydrates; the force which runs the factory. It is absorbed by the chlorophyll of the plant cells and transformed into available forms of energy. This process is not well understood. However, if the chlorophyll be extracted from leaves by boiling in water and then soaking in alcohol and the resulting solution studied with the spectroscope, it will be found that the red and blue rays are absorbed, while most of the green rays pass through the solution. This indicates that the red and blue rays furnish the energy and that leaves appear green because it is the green rays only that come to our eyes.

Composition of Chlorophyll.—We do not know the exact chemical composition of chlorophyll, but we do know that it contains carbon, hydrogen, oxygen, nitrogen and magnesium and that it is made up of several pigments, of which chlorophyllin (or cyanophyllin) is the most important. *Carotin* is always found mixed with the chlorophyll and was for a long time supposed to be a part of it, but is now believed to be independent. Carotin is also found in other parts of the plant, such as yellow flowers and fleshy roots. The chlorophyll and carotin may be very readily separated and studied by mixing the chlorophyll extract with benzene (four parts of the extract to one part of benzene), thoroughly shaking and allowing to stand for a time; the benzene rises above the alcohol. The benzene will contain the chlorophyllin, which is bluish green, and the alcohol will contain the yellowish carotin. Although the chlorophyllin is probably a distinct pigment, it is doubtful if it exist independently in nature. It appears to be closely related to the hæmoglobin of the blood, although the relationship is not well understood. The carotin is much more abundant than the chlorophyllin. It exists independently of the chlorophyllin and in various parts of the plant. It is very noticeable in the root of the carrot and the petals of many orange and yellow-colored flowers.

The leaves of many plants contain other coloring materials, sometimes in such abundance that we do not see the chlorophyll, but this is no evidence that they do not contain chlorophyll. The chlorophyll is present and active, but is concealed by the other colors.

Relation of the Stomata to Carbon Dioxide.—Although we have already referred to the stomata in connection with transpiration (page 172), their relationship to the intake of carbon dioxide is of as great or even greater importance. Therefore, their greatest activity in this connection will be in the presence of sunlight, *i.e.,* the time when photosynthesis is most active. The guard cells contain protoplasm and chloroplasts and are therefore capable of photosynthetic action. The formation of sugar in the cell sap of the guard cells causes a rise in their osmotic pressure, which results in the withdrawal of water from the neighboring cells into the guard cells and increases their turgidity. The outer wall of the guard cell appears to be more flexible than the inner wall; therefore, the increase in turgidity results in the opening of the stomata. There are many other factors that influence the action of the stomata, but in general it may be said that they are open during periods of photosynthetic activity (*i.e.,* during the day) and closed during darkness and as a result of wilting of the plant

Photosynthesis.—This may be considered as the most important process in nature. Briefly stated, it is the process by which the plant manufactures organic food. It is the result of the action of the sunlight on the chlorophyll in the presence of carbonic acid (*i.e.,* a mixture of water and carbon dioxide) at a favorable temperature. Therefore, the process involves chlorophyll, water, carbon dioxide, sunlight and a suitable temperature. The action of the sunlight on the chlorophyll results in the decomposition of both the water and carbon dioxide (H_2O and CO_2) and the formation of carbohydrates. The final result of this process is the formation of sugar or starch and the elimination of oxygen. This process may be expressed as follows:

$$\underset{\text{(Water)}}{6H_2O} + \underset{\text{(Carbon dioxide)}}{6CO_2} = \underset{\text{(Glucose)}}{C_6H_{12}O_6} + \underset{\text{(Free oxygen)}}{6O_2}$$

The liberated oxygen passes out through the cell walls and thence out through the stomata, where it becomes a part of the atmospheric oxygen.

However, it should be remembered that the formation of glucose (grape sugar) from H_2O and CO_2 is not a direct process, but is the final result of a number of intermediate processes which are very complex and not well understood. However, these higher carbohydrates, such as glucose and starch, are the first visible well-defined carbohydrate products of photosynthesis.

Photosynthesis probably begins with the dissociation of the elements which compose water and carbon dioxide. This requires a great deal of energy, and does not occur in nature, except in the presence of chlorophyll when acted upon by sunlight. This energy is not lost but stored up as latent energy in the form of sugar or starch and is available when these compounds are reduced to water and carbon dioxide. This latent energy is available for future use by the plant, for use by animals which feed upon plants and becomes very evident in the form of heat and light when plant materials are used for fuel. Therefore, the chlorophyll utilizes the energy from the sun and makes life possible on the earth.

Efficiency of the Food-Making Machine.—The green leaf under ordinary conditions absorbs and reflects about 50 per cent. of the sunlight which falls on it, but in diffused light it may absorb or reflect as much as 95 per cent. Only a small part of this (variously estimated from .5 to 3 per cent.) is used for photosynthesis. A considerable part is transformed to heat, and the temperature of the interior of the leaf may be a little higher than the surrounding air; in exceptional cases it may be 10 to 15 degrees higher. It has been estimated that a square meter of leaf surface will produce about one gram of organic matter in one hour. This work requires the CO_2 from 2.5 cubic meters of atmosphere.

Sugar and Starch Transformation and Migration.—It will be readily seen that grape sugar is formed only in the presence of chlorophyll and sunlight, mostly in the leaves of the plant. Other sugars are formed from the grape sugar. Sugar is soluble and can be readily transferred to other parts of the plant. Probably some of the sugar is transferred immediately, but if it is formed more rapidly than it can be removed, the excess is transformed into starch. In the presence of subdued sunlight and during the night, the excess starch is transformed into sugar again and removed to other parts of the plant, where it is either used for growth or stored as sugar or starch for future use. Sugar is found in great abundance in ripe fruits and in other parts of the plant, such as the roots of the sugar beet and the stem of the sugar cane (page 135). Starch is found in much greater abundance in fruits, seeds, fleshy roots and fleshy stems.

Formation of Other Foods.—The formation of carbohydrates by photosynthesis is only one step in the making of foods. We have already learned that plants contain carbohydrates, fats and oils, proteins and other compounds (page 139). The processes by which these and other compounds are formed is not clearly understood, but they involve other elements, such as nitrogen, sulfur, phosphorus, etc. (see page 201). The fats are composed of the same elements as are found in the carbohydrates, but the amount of oxygen is proportionately less. There are many kinds of proteins, but they all contain carbon, hydrogen, oxygen and nitrogen, and frequently sulfur and phosphorus. It is very generally believed that they are formed in the leaves, but sunlight does not appear to be a necessary factor.

LABORATORY EXERCISES.

Exercise 1. Select a plant with stomata on one side (*Coleus* or *Phaseolus multiflorus*) and keep in dark for 12 to 24 hours. Cover half of upper surface of one leaf and half of lower surface of another with vaseline. Expose to sunlight as long as possible. Remove as much of the vaseline as possible by wiping and place the leaves in warm 95 per cent. alcohol for 24 hours. When well bleached place them in a solution of iodine in potassium iodide. Examine for starch. Explain.

Exercise 2. Chlorophyll. Make an extract of chlorophyll by dipping leaves in hot water and then soaking in warm alcohol. Put in test tubes and examine under both reflected and transmitted light.

Exercise 3. Reduce the alcoholic extract to 80 per cent. Put 20 c.c. in a test tube and add 20 c.c. of benzole. Shake thoroughly and allow to settle. Note the color produced by the two pigments.

Exercise 4. Take two potted plants of the same kind. Keep one in the dark for 12 to 24 hours and expose the other to light during the day. Between 1 and 3 o'clock P.M. test the leaves of both for starch as in Exercise No. 1.

Exercise 5. Put some *Potamogeton* sp. or *Elodea* sp. under a funnel in a beaker of water. Put a test tube full of water over the tip of the funnel. Set in the bright sunlight and note the rise of gas in the tube.

Exercise 6. Remove an actively growing leaf from a plant early in the morning and another in the afternoon of a bright day. Place in boiling water for one minute and then in alcohol for a few hours to remove chlorophyll. Then in a solution of iodine. A blue color indicates starch. Which contains the most starch? Cut sections of both and examine.

Exercise 7. Soak red leaves of Coleus in a 5 per cent. aqueous solution of ether to remove the red coloring matter. Examine for chlorophyll.

Exercise 8. Grow seedlings in darkness. Expose one lot to light. Note the appearance of the green and compare the future growth of the two.

Exercise 9. Cover a growing plant and a glass of potassium hydroxide solution with a bell jar. The solution removes the CO_2 from the air. After a few days, test leaves for starch. Compare with a plant grown under a bell jar without potassium hydroxide.

CHAPTER XVII

MINERAL NUTRIENTS AND NITROGEN

Ash Content of Plants.—We have already learned that water constitutes about four-fifths of the ordinary herbaceous plant. If the plant is dried thoroughly and the remaining one-fifth of solid matter is burned in an open fire, we have a comparatively small amount of ash, which is usually about 1 to 3 per cent. of the original dry weight, although in some cases it is greater. The other 17 or 19 per cent. is organic material which has been volatilized. The ash contains the minerals of the plant, which have been obtained from the soil. The percentages of solids and ash for a few plants are given in the following table:

Product	Total Solids	Ash per cent of total product
Green corn fodder	20.67	1.16
Ripe corn fodder	89.44	1.53
Ripe wheat (grain only)	89.48	1.87
Green timothy hay	38.42	2.10
Green clover hay	29.21	2.10
Red beets	11.53	1.04
Cabbage	9.48	1.40
Lettuce	4.13	1.49
Cucumber	4.01	.46

The ash contains small amounts of practically all the minerals found in the soil in which the plant was grown. If the minerals of the soil are soluble, they will be taken into the plant, unless prevented by the plasmatic membranes of the root-hairs, which have a certain selective power (see page 163). The mineral elements most commonly found in plants are: phosphorus, potassium, calcium, magnesium, sulfur, iron, sodium, chlorine, silicon, manganese and aluminum.

The ash content of the plant varies with the different ages of the plant and in different parts of the plant. The development of the fruit and seed is usually accompanied by the translocation of certain mineral elements and compounds. Phosphoric acid migrates from the leaves and stems to the fruiting organs, and other elements and compounds are transported from place to place in varying amounts at different periods in the growth of the plant.

Origin of Minerals.—The soil is made up of ground rock and humus. The rock is ground up by the action of water and frost and many other natural agencies. In past ages the glaciers which moved downward from the north and spread over a considerable part of the eastern United States ground up the rock and distributed great quantities of soil and debris. The effects of these great ice movements are very evident to both the geologists and the botanists who make a study of plant distribution. Burrowing animals of various kinds and sizes also exert a much greater influence over the character of the soil than is generally appreciated. They bring a certain amount of subsoil to the surface and carry more or less organic material into their burrows for food and bedding, which decays and gives rise to acids which act on the surrounding soil. The burrows also afford excellent openings for the entrance of surface water. The ground materials from different kinds of rock are mixed in varying proportions by water and other natural agencies, and give rise to many well-known types of soil. It will be readily seen that these soils vary in different parts of the earth, dependent on the character of the material from which they are derived, and the action of water and other agencies. These variations, together with other factors, such as humus, water and temperature, are the controlling factors in plant distribution over the surface of the earth.

The Functions of the Mineral Nutrients.—A study of these elements in relation to plant growth brings out many important facts:

(1) We do not thoroughly understand the rôle of some of these elements.

(2) That the action of these elements varies when applied to different species of plants.

(3) That the action of these elements varies with reference to the amount in the soil.

(*a*) *Phosphorus* is a necessary part of the nucleo-protein of the cell and is found in comparatively large amounts in the seeds and in the seedlings. It has been noted that phosphorus migrates from the mature stems to growing tips and to seeds as they approach maturity.

(*b*) *Potassium* is an important factor in the formation of carbohydrates and proteids. If it is not present, starch is not produced and protein formation is abnormal. Furthermore, the cells elongate, but there is no nuclear and cell division. It has been noted that seeds and other parts of the plant rich in protein are usually well supplied with potash but without a definite ratio of the two compounds. Many fruit growers believe that potassium causes trees to ripen the wood better and is therefore a protection against winter and early spring injury from frost. It is also believed by many that it tends to improve the color and quality of apples, but this has not been demonstrated.

(*c*) *Magnesium* is believed to be an important factor in the transfer of phosphoric acid for assimilation. It is absolutely necessary for the development of chlorophyll. It is like phosphorus in that it is very abundant in growing tips and in seeds and may also be an important element in the nucleo-proteins. Under some conditions it is injurious to plant growth.

(*d*) *Calcium* is an important element in the metabolism of the plant. The use of lime on soils is very generally practiced in the growing of many crops. It is supposed to be an important factor in the functions of chlorophyll and there is some evidence of the definite relationship between the calcium in the plant and starch digestion. It has been demonstrated that the presence of calcium in the soil tends to counteract the toxic action of magnesium. It is also well known that if used in sufficient quantity it will overcome the acidity of the soil and make conditions more favorable for the growth of many plants.

(*e*) *Iron,* in very small quantities, appears to be necessary for plant growth, but its exact functions are not well understood. It is necessary for the formation of chlorophyll, and it is probably used in very small amounts by every living cell of the plant. When it is withheld, growing plants soon become pale or chlorotic and weak.

(*f*) *Sodium* is not required by plants, but may, under certain conditions prove beneficial. It may be advantageous to growing plants by making other salts available, especially potassium.

(*g*) *Chlorine* is not generally considered essential for plant growth, but may be important in some cases.

(*h*) *Sulfur* is very important and is essential in albuminous compounds. However, it is used in extremely small quantities.

(*i*) *Silicon* is very generally found in many plants, but does not appear to be necessary for their growth. It is utilized in many plants, such as horsetails or Equisetums, for mechanical strengthening of the cell walls.

Chemical Analysis of Plants and Soil.—From a study of the preceding, it will be readily seen that a chemical analysis of the plant is not always an index of the mineral elements which it needs. The presence of certain elements or compounds in the plant is not necessarily evidence that they are essential for the growth of the plant. Furthermore, a chemical analysis of the soil does not determine its value for plant growth. It may contain compounds in an unavailable form or the proportions may not be correct for the best results in crop production.

Nitrogen is an element which is necessary for plant growth, and, as we have previously learned, is one of the three most important constituents in commercial fertilizers. It is an essential element in protoplasm and proteins. It constitutes as much as 25 per cent. of the dry weight of some plants, especially members of the family *Leguminosæ* (see page 351). The high percentage of protein in the legume plants makes them valuable as food plants.

Source of Nitrogen.—We have previously learned (page 192) that the atmosphere ordinarily contains about 78 or 79 per cent. of free nitrogen. Although this free nitrogen is soluble in water and may enter and leave the plant cells in the same manner as the carbon dioxide and oxygen (page 195), yet the plant cannot use it in this free form. The green plant obtains its supply of nitrogen from the soil in the form of soluble nitrogen compounds, mostly nitrates of calcium, magnesium, potassium and sodium. These compounds exist in the soil, are dissolved by the soil water and taken up by the root-hairs by osmosis. Very low percentages of these soluble nitrogen compounds means that the soil is low in fertility. Although the amount of nitrogen in the soil is variable, arable soils usually contain about 1 to 3 per cent. The soil also contains nitrogen in the form of nitrites and ammonia compounds, which are sometimes poisonous to green plants and in most cases are changed to nitrates before they are used.

Soil nitrates and ammonia are derived:

(1) By the decay of organic materials of various kinds.

(2) By bacteria (*Pseudomonas radicicola*) which cause and live in the tubercles on the roots of leguminous plants.

(3) By certain bacteria and fungi which live free in the soil and are able to use nitrogen from the air.

(4) By ammonia carried to the soil by rainfall.

(5) By nitrous and nitric acid produced by lightning and carried down by rainfall.

Ammonification.—Dead plants and animals undergo decomposition (by means of bacteria and fungi) by which their nitrogenous compounds are broken into ammonia, carbon dioxide and other products. This is known as ammonification. The carbon dioxide returns to the air, but the greater part of the ammonia usually unites with soil acids or salts.

Nitrification.—The ammonification is followed by (1) the oxidation of the ammonium salts into nitrites and (2) the oxidation of the nitrites into nitrates.

Nitrifying Organisms.—It is now well known that certain bacterial and fungous organisms are capable of fixing the free atmospheric nitrogen which reaches the soil in the ways previously described into nitrates which can be used by plants. Some of these bacteria live free in the soil, but one of the most important of these is the bacterium *Pseudomonas radicicola,* which attacks the roots of leguminous plants, causing characteristic nodules (Fig. 104), in which the bacteria live and work. These organisms obtain their carbon, minerals and water from the leguminous plant and give in return the combined nitrogen which has been taken from the air by fixation. The great abundance of these organisms in connection with leguminous crops makes these crops very important as soil improvers. Leguminous plants growing without these organisms must obtain their nitrogen in the same manner as other plants and are of no more value as fertilizers than other plants.

The use of legumes for this purpose was recognized long be-

FIG. 104.—Nodules on the roots of a legume.

fore mankind knew anything about bacteria. The fungi which attack the organic materials in the soil and reduce them to soluble compounds are very generally referred to as molds. The relative value of these various organisms is not well understood.

Other Soil Organisms.—There are many other bacterial and fungous organisms in the soil, some of which are beneficial to agriculture, and others which are injurious. Among the latter are some species which tend to reduce the amount of nitrogen in the soil, still others cause diseases of plants and frequently cause heavy losses. Among the most interesting are the mycorrhizal fungi which are found associated with the roots of many higher plants.

They grow in and on the roots, forming a structure which absorbs the soil water very readily. In most cases they are considered as being beneficial, and some plants, such as the blueberries and the Indian pipe, will not grow if the fungus is not present. In some few cases they are believed to be injurious. Many of the large fleshy fungi (toadstools and mushrooms) produce mycelium growths in the soil; in most cases they are saprophytic, but some of them are parasitic on the higher plants and the cause of losses in crop production. Some of the very small green algæ (see page 260) grow in the surface strata of moist soil, but their influence on the soil is not well understood. Some soils contain great numbers of unicellular animals, known as *Protozoa.* They feed on bacteria, and it is very generally believed that their presence is injurious to the soil.

Water Cultures.—Water cultures are very generally used to demonstrate the nutrition requirements for plants. They consist of mineral solutions with seedling plants suspended at the surface, so that the root systems will be submerged. The most common solutions are:

1. Pfeffer's Solution.

Calcium nitrate	4 grams
Potassium nitrate	1 gram
Magnesium sulfate	1 gram
Potassium dihydrogen phosphate	1 gram
Potassium chloride	5 grams
Ferric chloride	trace
Distilled water	3 to 7 litres

2. Crone's Solution.

Potassium nitrate	1.00 gram
Ferrous phosphate	.50 gram
Calcium sulfate	.25 gram
Magnesium sulfate	.25 gram
Distilled water	2.00 litres

These solutions can be varied by the removal of certain compounds and some idea obtained as to the exact needs of the plant.

If glass jars are used, they should be covered with black paper to prevent the growth of algæ, which will interfere with the experiments.

Since the plants will use these minerals the solutions should be changed frequently.

Balanced Solutions.—It is very generally recognized that any nutrient salt used alone may prove injurious to plant growth. It is also well known that the nutrients in a solution or soil must bear a definite relation in order to secure the most satisfactory plant growth. In recent years it has been learned that the injurious effects of some of these nutrients may be overcome by the use of others. Solutions in which these antagonistic nutrients are properly mixed in order to give good results are known as "balanced solutions." The magnesium compounds are toxic to most of our higher plants, but this toxicity can be overcome by the proper use of lime. Therefore, when soils contain an abundance of magnesia, it is usually necessary to use lime, but care should be taken to use a grade of limestone relatively free from magnesia. It will be readily seen that a knowledge of balanced solutions becomes a very important factor in the study of fertilizers.

LABORATORY EXERCISES.

Exercise 1. Prepare a quantity of Pfeffer's and Crone's solution and fill several wide-mouthed bottles that have been covered with black paper.

Prepare Pfeffer's solution, omitting the ferric chloride. Put in bottles as above.

Prepare Crone's solution, omitting the ferrous phosphate. Put in bottles as above.

Select seedlings that have been grown in wet sawdust or moss and are uniform in size. Suspend in the glasses by the use of notched corks. Compare the growths in the various solutions.

Exercise 2. Similar experiments may be made by using other modifications of these solutions.

CHAPTER XVIII

METABOLISM—DIGESTION—TRANSLOCATION—GROWTH

Interrelationship of Organs.—The higher plant is a very complex organism, consisting of many types of cells and tissues, of systems and organs. These organs serve many complex physiological functions in the life history of the plant and are interdependent upon each other. Water is absorbed by the roots, and transported through the stems to the aerial parts, where a part of it is used for the making of foods and a part given off by transpiration. The water carries the minerals which are also used in the making of food and the soluble foods to various parts of the plant for use or storage. The stems serve for transportation and other purposes. The leaves serve for photosynthetic and other food-making processes and for transpiration. The flowers serve for reproduction. Therefore, it is very evident that an equilibrium must exist between the various parts of the plant if it is to perform its functions to the best advantage.

Metabolism.—Having studied the taking in of water and the various raw foods which it carries in solution, the transpiration of water, the taking in of carbon dioxide, and photosynthesis, we will now turn our attention to the complex activities of the plant which involve growth. All the above processes must precede or accompany growth, which involves the utilization of grape sugar and other true food compounds which are manufactured by the plant. These true food compounds are used directly in the making of protoplasm, or they may be stored for the time and used later.

Protoplasm has the power of making new protoplasm and practically all the other plant products found in the plant, such as cell walls, sugars, starches, fats, oils, resin and alkaloids, are made either directly or indirectly from protoplasm.

We will now turn our attention to some of these very complex chemical activities of the plant. The first of these is *metabolism*, which involves both constructive (*anabolic*) and destructive (*catabolic*) processes of growth. These processes include the breaking down of the true foods: carbohydrates, fats and oils, and proteins, which have been manufactured by the plant, and their utilization in the making of protoplasm, in the growth of the plant, and the formation of the many plant products. Some of these products become permanent plant structures, others are temporary and for immediate use by the plant, others are stored for future use, and others are apparently by-products so far as their use by the plant is concerned and may be thrown off or retained within the plant.

Some of the most important of these metabolic products are the protoplasm, sugars, starches, fats and fatty oils, proteins, cellulose, cutin, suberin, lignin, volatile oils, glucosides, acids, tannins, alkaloids, pigments and enzymes. Some of these plant products are utilized by man and are of great commercial value.

The building up of the various parts of the plant is a constructive or *anabolic* process. But the constructive processes cannot be carried on without the breaking down of existing compounds which are to be used in construction and the repair of a part of the machine which is doing the work; that is, catabolic processes. Therefore, the various activities of the plant, such as absorption of aqueous solutions, translocation of crude food materials, the absorption of sunlight, the manufacture and translocation of the true food compounds, the transformation of compounds from one form to another, the making of the various plant products, and growth—all involve *catabolism.* Therefore, we find numerous waste products; *i.e.,* waste, so far as the plant is concerned, although many of them are of commercial value. They are the gases and water which are given off by the plant; the bark, leaves and twigs which are shed by the plant, and many other materials.

Digestion.—This is the changing of the true food materials into soluble products. All food materials must be digested by the plant before they can be moved from place to place or used for growth or repair. In some cases the plant may use the food as soon as it is formed, but in most cases it uses the foods which have been stored up for this purpose. The plant has no stomach or other specialized organ for digestion, but the work of digestion is carried on in the cells and is most prominent in the germination of seeds, tubers and bulbs and in all new growths. These organs serve for the accumulation or storage of insoluble starches and other food materials which must undergo a digestion in order to render them soluble. In this soluble form they are transmitted to the various parts of the plant and used in the processes of growth.

The digestion is very generally accomplished by means of ferments or enzymes which are produced by the living protoplasm, and are of the same character as those produced by the animal. In fact, the chemical processes of digestion are practically the same in the plant as in the animal. These enzymes are nitrogenous bodies, and there are no doubt many different kinds which act on many different kinds of plant products.

Some enzymes act by causing oxidation, but most of the common ones act by causing hydration, and the process may be illustrated by the following:

$$\underset{\text{(Sucrose)}}{C_{12}H_{22}O_{11}} + \underset{\text{(Water)}}{H_2O} = \underset{\text{(Dextrose)}}{C_6H_{12}O_6} + \underset{\text{(Levulose)}}{C_6H_{12}O_6}$$

Some of the more important of these enzymes are (*a*) the *diastases,* which act on starches; (*b*) the *cystase,* which acts on cellulose, and (*c*) the *proteolitic enzymes,* which act on proteins, etc. The enzymes are of the very greatest importance in germination, in growth, in the ripening of fruits and in many other activities of the plant. In fact, all the chemical processes of the plant are probably the results of enzyme activities.

Translocation.—The digested products are soluble and in this form are transported to the various parts of the plant for use in growth. This is by no means thoroughly understood, and it no doubt varies in both quantity and character of materials at different seasons of the year and at different periods in the plant's growth. We have already referred to the fact that sugars are carried in the cell sap through the xylem parts of the fibro-vascular bundles and that the digested proteins are carried in the sieve tubes of the phloem of the same structures.

It is very generally said that the movement through the xylem is upward and the movement through the phloem is downward, but these statements do not account for all the movements of plant products in the plant. The presence of sugar and starch in tubers, bulbs and fleshy roots is a proof that these compounds are carried downward from the chlorophyll-bearing parts in which they are produced. It is very evident that the movement of liquids within the plant is not well understood.

The carbohydrates and other products which are manufactured in the green parts of the plant must be transferred to other parts of the plant for immediate or future use, except in those plants in which the leaves serve for storage. Therefore, practically all of the stored materials found in fruits, seeds, tubers, bulbs and fleshy roots have been manufactured in the leaves and transferred to these parts for storage. We have called attention to the translocation of the various minerals.

Assimilation.—This is a process which very naturally follows digestion and which precedes growth. It is the transformation of true foods of the various kinds into living protoplasm. Foods must be assimilated by and become a part of the living protoplasm before they can be used for growth or for repair. Assimilation will not be thoroughly understood until we have a thorough knowledge of the chemistry of living protoplasm and of the compounds from which it is developed.

Reserve Foods and Storage.—Although the plant makes its own true foods from the raw materials which it secures from the soil and air, it does not necessarily use them immediately. We have already learned that foods may be stored in stems, roots, leaves and seeds to be used by the plant at some future time. The character of this stored food, the absence of undesirable plant products and the character of the plant structures are important factors in determining the value of the plant as a food for man and live stock. Carbohydrates, fats, oils and proteins are the most common forms of storage products found in plants (see Chapter XI). These plant products must undergo digestion before they can be assimilated and used for the growth of the plant.

Growth.—This is a process which we very vaguely describe as the enlargement of the living organism. We now realize that it is a very complicated process and involves many activities, some of which are chemical and others of which may be purely physical. Growth involves practically all the very complex processes which we have studied and many others. Furthermore, it is influenced by many external or environmental factors. The evidences of plant growth are the increase in size and weight, the formation of cells, tissues and organs, and reproduction. A more thorough study shows cell enlargement and division, formation of cell walls, differentiation of tissues and secondary thickenings.

We see evidences of growth in the germination of seeds, in the elongation of roots and shoots, in the enlargements of leaves, in the formation of flowers and fruits, and in the thickening of many parts. We now know that this growth involves the taking in of water, carbon dioxide, nitrogen and minerals, the absorption of energy from the sun, the manufacture of true foods, the transportation of foods, and the utilization of foods in the formation of new cells. We have also learned that some growths, such as the development of the embryo and cell modifications, are very obscure; and we have also learned that a plant may increase in size and not increase in dry weight. Although our previous work has involved a continuous consideration of growth, there are some few points that should be given special consideration at this time.

Storage of Foods and Growth.—The stored foods in the plant serve primarily for the growth of the plant at some later period. This is well illustrated in the case of the seeds, the stored food serving for the support of the seedling until its roots have penetrated the soil and its leaves have spread out into the air. It is also seen in bulbs, tubers, fleshy stems, roots and leaves, in which the stored food feeds new plants or is used in the producing of flowers, fruits and other organs.

Phases of Growth.—There are very naturally three phases of growth: (1) the origin and formative phase, (2) the enlargement and elongation phase and (3) the maturing phase.

The origin and formative phase involves cell divisions, the formation of new tissues and the production of new organs. It is especially prominent in the growth of the seedling, in the growth of shoots and leaves in the spring and usually in the formation of flowers and fruits. The enlargement phase involves the enlargement of cells and organs, and varies in different parts of the plant and at different seasons of the year. We have already learned that there is a zone of elongation in the root tip (see page 67) and in the tips of growing shoots (see page 46); and that the thickening of the dicotyledonous stems and roots is due to the growth and cell division in the cambium (see page 48). The enlargement of buds, shoots, leaves, flowers and fruits at certain seasons of the year is very evident to the most casual observer. The maturing phase involves cell-wall thickenings and many complex physiological and chemical changes. The maturing of buds is very necessary in order to prepare the plant for the winter season of our temperate zone. The maturing and ripening of fruits and seeds is a phenomenon with which we are all familiar, but which involves chemical processes which we do not thoroughly understand.

In general, it may be said that the ripening of fruits involves the breaking down of the cell walls and the changing of starches into sugars as a result of the action of the enzymes. These changes will go on in stored fruits and vegetables. Cold storage is used to hold these activities in check.

Location and Rate of Growth.—We have already learned that growth is localized in the plant body. The most active cell division is in the meristematic system, which in our higher plants means the primordial meristem at the tip of the stem and the cambium of the stems and roots (see Chapter III). The enlargement of the cells, the thickening of the cell walls and other internal evidences of growth have also been discussed.

The *rate* of growth varies with the species of plant, the part of the plant, the season, the time of the day and the environmental factors.

(1) It is very generally recognized that some species of plants grow very rapidly, while others grow very slowly: the hardwood trees grow very slowly, only a few inches in a season, while many of our agricultural crop plants attain their full growth in a very short season. Many weeds grow faster than the crop plants, and it is necessary to cultivate the crop as a means of protection against them.

(2) The younger parts of many plants elongate very rapidly. We have already called attention to the zone of elongation in the roots (page 67). The tips of the stems also elongate very rapidly, in some cases one or two or three or more inches in twenty-four hours. The elongations can be very readily measured by special instruments (auxograph and auxanometer).

(3) In the temperate zones the spring and summer are very generally recognized as the seasons of growth, and the fall and winter as the seasons of rest. It is also very generally recognized that some plants make the major part of their growth during a very short period and that the remainder of the season is utilized

in internal growth and the making of foods. Many tropical plants also have more or less well-defined seasons of rest. However, some plants would grow indefinitely if the weather conditions were favorable; we have already called attention to some of these plants with indefinite growth (see page 42).

(4) It is well known that many plants grow more rapidly during the night than during the day. This may be due to the fact that intense light has a tendency to inhibit or check plant growth. However, the carbohydrates which the plants use to provide energy for growth were made in the presence of sunlight.

(5) The most important environmental factors which influence or control plant growth are moisture, temperature, sunlight and character of soil which have already received consideration in the preceding chapters.

Irritability.—A comparison of plants growing under different environments, under favorable and unfavorable conditions, is evidence of the response of the internal activities of the plant to the external or environmental factors. Since the protoplasm is the center of all activity on the part of the plant or any other living organism, we naturally turn to it for an explanation of these phenomena. It can be readily demonstrated by experimental work that the protoplasm of the active cell responds to stimulation with heat, light, chemicals, electricity, etc. This can also be observed on the growing organs of the higher plants, which respond to various environmental factors; roots seek darkness and moisture, while the leaves turn towards the sunlight, the entire plant responding to these and many other factors, such as mineral foods and temperature.

The twining of such plants as the morning-glory and the twisting of tendrils of such plants as the grape are good illustrations of the response of the plant to a contact or touch stimulus. The tip of the plant or tendril swings in a more or less regular circle (nutation) until it comes in contact with some object. The irritability of the part causes it to respond to this stimulus by twining or twisting.

Plant Movements.—It is well known that growing plants have the power of making certain well-defined movements, which are no doubt the result of some one or more of the various irritants or environmental agencies. In some plants (*Desmodium gyrans*) there is a constant rising and falling of the leaflets. The mature stamens of the barberry fly upward when touched, and the pollen is expelled at the same time; since insects are constantly coming in contact with the flowers this movement aids in pollination. The tentacles on the leaves of the sundew (*Drosera*) move when touched and capture many insects which come in contact with their viscid tips. The leaves of many plants move under the influence of light and darkness and also under the influence of temperature.

Tropism.—This term is used to apply to certain curvature movements of the plant with which we are all more or less familiar, but which are so common that we usually give them very little consideration. Among the most important of the tropisms are: (1) *Geotropism,* which refers to the downward movement of roots and appears to be due to the force of gravity as the stimulant. (2) *Heliotropism* (or *phototropism*), which refers to the movements of organs, especially the leaves, towards sunlight, which is the stimulant. These two tropisms result in bringing the stems of most plants into a more or less upright position, although it must be remembered that some stems are underground and are not influenced by the sunlight. (3) *Thigmotropism,* which refers to the twining of the stems or other organs of climbing plants; friction, resulting from contact of the sensitive organ of the climber with some other object being the stimulant. (4) *Hydrotropism,* which refers to the movement of organs, especially roots, towards moisture, which is the stimulant. Note that geotropism and hydrotropism usually work in combination. (5) *Aerotropism,* which refers especially to the movement of roots into soil in which there is an abundance of air, which is the stimulant. Aeration of the roots is a very important factor in the growth of many plants, and explains in part the necessity for cultivation of many of our crops. The bald cypress, which grows best in swamps, produces peculiar outgrowths (knees) from the roots which rise into the air. (6) *Chemotropism,* which refers to the growth movement of parts towards or away from chemical compounds which may be useful or injurious. This is well illustrated by the growth of the pollen tube through the style and into the micropyle and also by the growth of hyphæ of fungi towards food.

All these tropisms are growth movements and are restricted to the young and growing parts of the plant. As the roots and stems increase in age they become less and less mobile and finally become immovable. When young plants are beaten down by wind and rain storms, they will frequently resume their normal positions in part or entirely; but when large trees are blown down they cannot resume their original position. However, the new growth will assume positions in accordance with the tropisms by which they are influenced.

Relation of Plant Organs to Sunlight.—It is well known that plants growing in a window develop so as to bring the leaves into the proper light relationship. Also that potatoes which germinate in darkened cellars produce long shoots which grow in the direction of the light. Plants in the open are subject to the same laws and the direction of stem growth and arrangement of foliage is influenced by the direction and intensity of the sunlight. The leaves on such vines as the Boston ivy and the grape assume positions with reference to the sunlight. The leaves on a tree are usually near the tips of the shoots and thus form a canopy. Trees in dense forests tend to grow tall, because the sides are shaded by other trees, while trees of the same species in the open tend to produce broad, low, dense heads. The lower branches of trees growing in dense forests die and fall largely because they do not receive the necessary sunlight.

LABORATORY EXERCISES.

Exercise 1. Mix one gram of flour in 100 c.c. of H_2O and boil. Put 2 c.c. in each of ten test tubes. Add boiled diastase to two test tubes, and fresh unboiled diastase to the other eight. Test two of the eight for sugar immediately, two at the end of 30 minutes, two at the end of one hour, and two at the end of 24 hours. Also test the two with the boiled diastase at the end of 24 hours.

Exercise 2. Translocation. Select active growing Geranium, Fuchsia or other plants. Expose to bright sunlight for three or four hours. Remove two or three leaves; dissolve the chlorophyll and test for starch. Set the plant in the dark for four or more hours and test another set of leaves in the same manner.

CHAPTER XIX

RESPIRATION—AERATION—FERMENTATION

Respiration.—This term was first used and is still used in reference to the breathing of animals. For a long time it was supposed that plants breathed in very much the same manner as animals, and therefore it was used to refer to the breathing of plants. But we have already learned that plants do not breathe in the same manner as animals. The air is not taken in and forced out as in the animal, but there is an exchange of atmospheric gases by diffusion (see page 173). The term "respiration" more strictly refers to the catabolic process in the individual cell, whether animal or plant. It occurs in all active cells throughout the plant and is not restricted to the leaves. It requires oxygen, part of which is obtained as a result of photosynthesis and part of which is taken in through the leaves in the same manner as the carbon dioxide (see page 195) and then transferred to other parts of the plant in solution. It may also obtain oxygen as a result of the metabolic activities of the cell. When the carbon of the starches, sugars and other compounds of the cell unites with the oxygen, heat is liberated, but most of it is again utilized by the plant. This process can be illustrated by the following formula:

$$\underset{\text{(Grape sugar)}}{C_6H_{12}O_6} + \underset{\text{(Oxygen)}}{6O_2} = \underset{\text{(Carbon dioxide)}}{6CO_2} + \underset{\text{(Water)}}{6H_2O}$$

The heat causes the temperature of the plant to be a little higher than the surrounding atmosphere. The by-products of respiration, that is, the carbon dioxide and water, may be used by the plant or returned to the air through the leaves.

Respiration and Photosynthesis.—(1) Respiration occurs in the protoplasm of the cells throughout the plant, while photosynthesis occurs only in the chloroplasts. (2) Respiration is a process of oxidation and breaking down of compounds resulting in the liberation of latent energy, while photosynthesis is a process of building up of compounds and storage of latent energy. (3) Respiration uses oxygen and liberates water and carbon dioxide, while photosynthesis uses water and carbon dioxide and liberates oxygen. (4) Respiration is active in the presence or absence of light, but photosynthesis requires sunlight. (5) Photosynthesis is carried on by the energy derived from sunlight and life processes are carried on by the energy derived from respiration.

Respiration and Starvation.—When animals are deprived of food they lose in actual weight, regardless of the supply of water and air, because they are using their reserve or stored supply of food. In the same manner a green plant deprived of sunlight, which is necessary for the formation of true plant food, but supplied with all necessary water, air, minerals and nitrogen, will lose in actual or dry weight, because it is also using its reserve or stored supply of food. The animal must have organic food from which to construct its own tissues. The plant manufactures its own food from the raw materials and this cannot be done without sunlight. Therefore, depriving the animal of organic food and the plant of sunlight result in starvation. Seeds germinated in total darkness will increase in total bulk, but decrease in actual dry weight, because the reserved foods are used in the process of growth. This loss of weight is due to the respiratory processes of catabolism which go on in every active plant and animal cell. We have already learned that catabolism is a destructive process which must result in loss of weight and energy unless the anabolic activities are greater than the catabolic activities. Growth and both internal and external activity of the cells are evidences of respiration. It always results in the taking in of oxygen and the giving off of carbon dioxide. In the germination of seeds the absorption of oxygen is greater than the elimination of carbon dioxide, but in the actively growing green plant this ratio is reversed.

Respiration and Germination.—We have learned that respiration occurs in the protoplasm of the living cell and that it is most active during the period of greatest growth. Therefore, we will expect the respiration processes to be very active during the period of seed germination and seedling growth. In fact, during the period of germination the plant requires much more oxygen and gives off much more carbon dioxide in proportion to its size than at any other period in the growth of the plant. During this period of very great activity, the temperature may be 10 degrees C. or even 20 degrees C. higher than the surrounding atmosphere.

During the period of germination the plant has little or no chlorophyll, and, therefore, uses but very little or none of the carbon dioxide for photosynthesis. It is living and growing on the reserve food, must use oxygen and must give off carbon dioxide. With the development of the chlorophyll it performs photosynthetic work and builds tissues.

Diffusion and Absorption of Oxygen.—Since oxygen is one of the free gaseous elements of the air, it must necessarily pass by diffusion into the stomata, where it comes in contact with delicate and moist walls of the internal cells. Therefore, a certain amount of oxygen is absorbed (see page 193) by the cell sap and finally reaches the protoplasm, where it becomes a factor in the catabolic activities of the cell. As a result of these activities, a certain amount of carbon dioxide and water are eliminated and kinetic energy released. A part of this energy is used in plant growth and a part is set free as heat. It is very evident that respiration is greatest during the period of most active growth and in those parts of the plant where the growth is most active. Germination is the period of greatest activity in plant growth and therefore the period in which respiration is the greatest. Rapidly germinating seeds may lose 3 per cent. of dry weight per day during the first ten days of germination. It is also well known that respiration is greater in wounded than in uninjured plants.

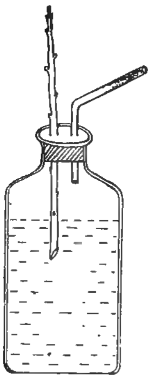

FIG. 105.—Device for demonstrating the connection between the lenticels and the intercellular spaces of the stem

Aeration.—Since both the carbon dioxide and the oxygen of the atmosphere are necessary for plant growth and since the plant eliminates both of these gases and also water, it is very evident that the plant must have a suitable atmospheric environment. This is brought about by the wind movement of the air, which is thus kept in constant circulation and is thoroughly mixed. In the case of young leaves there may be some exchange of gases through the walls of the outer cells, but in the case of mature leaves the outer walls are cuticularized, which prevents any such exchange. Therefore, the exchange must be through the walls of the cells which line the intercellular spaces and which are connected with the outside by means of stomata. Here again the law of diffusion becomes an important factor, for it is by diffusion that air in the intercellular spaces is being constantly renewed. Air also enters the stem through the lenticels (see page 53 and Fig. 105).

Aeration of the soil is also an important factor in plant growth. There is a very evident interchange of atmospheric gases in the root system of the plant. If the free aeration of the soil is prevented by a packing of the soil or by saturation of the soil with water, many species of plant are unable to grow. Furthermore, the micro-organisms must receive nitrogen and other atmospheric gases from the air. Therefore, the proper drainage and cultivation are important factors in agriculture.

Fermentation.—This term was originally applied to the souring and decomposition of organic substances. It is due to enzymes which are produced by bacteria or other organisms. Among the most common of these is (*a*) the fermentation of milk by lactic acid bacteria. It may be illustrated as follows:

$$\underset{\text{(Lactose)}}{C_{12}H_{22}O_{11}} + \underset{\text{(Water)}}{H_2O} = \underset{\text{(Glucose)}}{C_6H_{12}O_6} + \underset{\text{(Galactose)}}{C_6H_{12}O_6} = \underset{\text{(Lactic acid)}}{4(C_3H_6O_3)}$$

The bacteria use a part of the sugar as food and produce lactic acid, carbon dioxide and sometimes other organic acids, hydrogen and nitrogen. The formation of lactic acid interferes with the action of the various bacteria found in milk and their activities usually cease when the liquid contains about .8 per cent. of acid. (*b*) Alcoholic fermentation of sugar solutions, which is most commonly caused by yeast. When O_2 is abundant the yeasts grow rapidly, using the sugar for food and causing very little fermentation, but when the amount of O_2 is low the yeasts grow slowly and fermentation is more rapid. It may be expressed as follows:

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} = \underset{\text{(Ethyl alcohol)}}{2(C_2H_6O)} + \underset{\text{(Carbon dioxide)}}{CO_2}$$

The activity of the yeasts is practically inhibited when the liquid contains 14 per cent. of alcohol. They are used in the manufacture of alcoholic beverages and in the making of light bread. The bubbling of the CO_2 through the dough of wheat flour is the most important factor in bread-making. (*c*) Acetic fermentation, which is caused by bacteria acting on alcoholic solutions. It may be illustrated as follows:

$$\underset{\text{(Ethyl alcohol)}}{C_2H_5OH} + O_2 = \underset{\text{(Acetic acid)}}{CH_3COOH} + \underset{\text{(Water)}}{H_2O}$$

This is the action in the transformation of cider into vinegar.

It will be readily seen that all of these fermentations are in fact respiration processes within the bacteria or fungi involved.

Anaërobic Respiration.—Respiration processes are sometimes carried on without free oxygen, and some of the micro-organisms perform the functions of respiration to the best advantage in the absence of oxygen. This is known as *anaërobic respiration* and is characteristic of certain bacteria and fungi. It results in the formation of CO_2 and sometimes of alcohol, lactic acid and hydrogen. It is evidently due to a rearrangement of the atomic groups in the organic molecules. Anaërobic respiration probably precedes the aërobic or ordinary respiration in all cases, but this is not well understood.

LABORATORY EXERCISES.

Exercise 1. Select two lots (about 24 each) of beans or peas of about the same weight. Heat one lot and determine the dry weight. Germinate the other lot in wet filter paper in a dark closet. When the seedlings have attained their maximum growth under these conditions, dry and determine the dry weight. Compare with the first lot. Have they lost or gained in weight?

Exercise 2. Put beans or peas that are just beginning to germinate into two wide-mouthed bottles. After 12 to 24 hours test the air in one with a lighted taper and the other with baryta water. Make similar tests with the air in empty bottles. Explain.

Exercise 3. Select three large glass evaporating dishes, A, B and C.

Place a glass bell jar with an opening at the top in each. Put fresh active green shoots into A and B. Put a burning candle (2 or 3 inches high) supported by corks under each jar. Pour water into the dishes until it rises 2 or 3 inches. Put corks into the tops of the jars and note the effect on the flames. Explain. Cover jar B with a heavy black cloth and set all three in strong sunlight for three hours. Lower a lighted taper into each and note the effect. Explain.

Exercise 4. Put 10 per cent. sugar solution of glucose, sucrose, and lactose each into two fermentation tubes as directed by the laboratory instructor. Put a fragment of good yeast into each, plug with cotton and set aside for twenty-four hours. Test those showing gas by inserting a stick of caustic potash. Explain.

Exercise 5. Pour 500 c.c. of modified Pasteur's * solution into a one-liter Erlenmyer flask; add two grams of good yeast. Close the flask with a cork carrying the short arm of a bent glass tube, the long arm so bent as to reach a wash bottle. Allow the fermentation to drive out the air; then insert the long arm into a bottle of baryta water. Note the effect and explain.

Allow the flask to stand for a week so as to permit complete fermentation. Test a small amount of the liquid for glucose.

Exercise 6. Add yeast to a 4 per cent. sugar solution. Examine in 24 hours and note the formation of gas. Test for sugar.

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* Water	500 c.c.
Glucose	75 grams
Ammonium tartrate	5 grams
Potassium di-hydrogen phosphate	1 gram
Calcium chloride	.5 gram
Magnesium sulfate	.5 gram

CHAPTER XX

TEMPERATURE AND LIGHT

Environmental Factors.—The living plant is influenced by its environmental factors, such as water, food supply, heat, light and many others too numerous to mention. It is doubtful if any of these factors are ever exactly right for the best growth for any considerable time. Therefore, the plant may be considered as having made the best possible growth under an environment which is never absolutely perfect. Very naturally, the more satisfactory the environment with regard to all its many factors the better the plant that will be produced. We have already considered some of these environmental factors, such as water and the food supply.

Plant Geography.—The natural distribution of plants over the surface of the earth is controlled by these environmental factors. This is very noticeable in the north and south boundaries of certain plants, which are evidently due to temperature. It is equally true where the limiting factors are due to water supply and character of the soil. When crop plants are introduced from one part of the world into another part these environmental factors must be taken into consideration if the introduced crop is to prove successful. A study of the native and agricultural plants of the country enables us to map out certain regions which are referred to as the pine regions, the hardwood regions, the corn belt, the cotton belt and the rice districts.

Temperature.—Plants grow under a very wide range of temperature from the equator to the polar regions; from the low valleys to the high mountains. Some of the algæ grow in hot springs, where the temperature approaches the boiling point, while others grow in the arctic regions of perpetual snow. Some plants are restricted to definite and limited regions by the temperature, while others grow over a very wide range of territory and under great variations of temperature. Some of these plants attain considerable size under favorable temperate climates, but are very small when grown in extremely low temperature. The effects of temperature on vegetation can be readily seen when we study the changes in vegetation as we ascend from the base to the top of very high mountains. The distribution of many of our agricultural crops is controlled largely by the temperature.

Maximum, Optimum and Minimum Temperatures for Germination.—These terms refer to the highest, most favorable and lowest temperatures for germination and plant growth. These temperatures are different for different species and are frequently different for germination and growth in the same plant. A few are given in the following tables:

Temperature for Germination in C. Degrees.

Plant	Min	Opt.	Max.
Corn	9.4	34	46.2
Pumpkin	14.0	34	46.2
Wheat	5.0	34	42.5

Temperature of Growth in C. Degrees.

Plant.	Min.	Opt.	Max.
Buckwheat	0-4.8	25-31	37-44
Oats	0-4.8	25-31	31.37
Wheat	0-4.8	25.31	31.27
Peas	0-4.8	25-31	31-37
Corn	4.8-10-5	37-44	44-50
Pumpkin	10.6-15-6	37.44	44-50
Cucumber	15.6-18-5	37.44	44-50

Temperature of the plant is approximately the same as the temperature of the air, but in the presence of sunshine may be slightly higher (see page 197). There is very little or nothing in the way of plant structures for direct protection against changes of temperature which may be injurious to plant growth. It is true that buds may have well-developed coverings of scales, abundance of hair or resin deposits; but these protect against loss of water rather than against external temperature. However, some of the external structures protect to some extent against sudden changes of temperature.

Freezing.—The freezing of most living plants is very generally recognized as injurious, but it should be remembered that many plants, such as wheat, rye, clover and vetch, remain green and grow to some extent during the winter. Their ability to thrive at low temperatures makes them valuable as cover crops. In the first stages of freezing, the ice crystals are formed on the surface of the cells, usually in the intercellular spaces. It is very generally believed that in this process the water of the cell gradually passes through the cell walls into these intercellular spaces. The extent of the injury due to freezing appears to be due to the degree to which the cell gives off water. However, this question is subject to differences of opinion.

Light.—The necessity of light for photosynthetic work has already received consideration (see page 195) and we have learned that sunlight (or its equivalent, *i.e.,* the proper kind of artificial light) is absolutely necessary for plant growth. However, the amount of sunlight necessary for plant growth is not the same for all species of plants and, therefore, plants do not always grow under the most favorable sunlight conditions. The sunlight may be too weak or too intense for the best growth.

It is very generally recognized that many plants grow most rapidly during the night; this is partly due to the retarding action of the sun's rays and partly due to the greater humidity of the atmosphere, but the growth is always with the food that

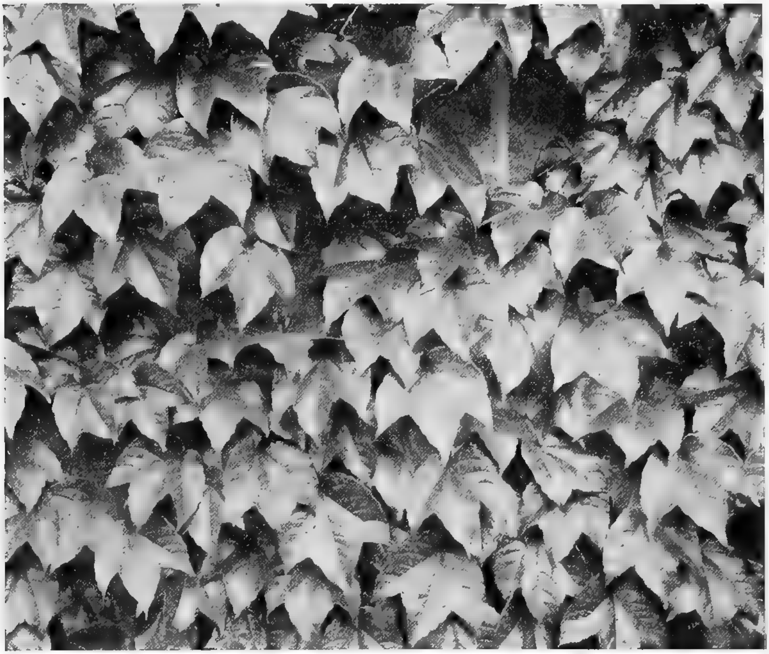

FIG. 106.—Ivy leaves on a wall showing the arrangement with very little overlapping.

was manufactured during the day. It is also well known that sunlight will kill many species of bacteria.

Relation of Plant to Sunlight.—It is well known that plants growing in a window develop so as to bring the leaves into the proper light relationship. Also that potatoes which germinate in darkened cellars produce long shoots which grow in the direction of the light (see page 218). Plants in the open are subject to the same laws and the direction of stem growth, character and arrangement of foliage, are influenced by the direction and intensity of the sunlight. Trees growing near objects which shut off the light from one side will not spread uniformly. Trees growing in the open usually have short trunks and broad, rounded tops, but trees grown in the forest mass must compete with each other for the light and therefore grow tall and slender. The lower branches of the trees growing in the dense forest die prematurely and fall largely because they do not receive the necessary sunlight. The grape and other climbing plants are influenced in their direction of growth by the sunlight; when growing in the forests they tend to grow to the top of the tallest trees. Many plants that ordinarily grow and thrive in the direct sunlight will make very tall, slender growths under partial shade conditions. This principle is utilized in the growing of corn and sorghum for fodder or silage, where it is desirable to develop small stems especially suitable for stock feed.

Relationship of the Leaves to Sunlight.—The arrangement of the leaves on the stem is correlated with the sunlight. The alternate, opposite and whorled arrangements are such as to bring the foliage into the most satisfactory position with regard to the sunlight. The leaves on the tree are usually near the tips of the shoots and thus form a canopy. The leaves on the tips of these branches are usually so arranged as to produce a minimum of shading. Looking down upon a tree, the leaves will be seen to form a very excellent mosaic. The leaves of the Boston ivy and similar plants are also arranged so as to produce a mosaic, which is the best arrangement for the sunlight relationship (Fig. 106). The form of the leaves and length of petioles are also correlated with the sunlight needs of the plant. The plants with acaulescent stems have leaves with petioles of varying lengths which prevents overlapping and shading to any great degree.

Influence of Light on Plant Distribution.—Light influences the distribution of plants in a manner somewhat similar to water, temperature, soil and other environmental factors. Some plants are known as lovers of sunshine and are usually found where the sunlight is intense. Others thrive best in subdued light and are very generally found growing in the shade of trees and other plants larger than themselves. Therefore, many forests show strata of plant growths: (*a*) the trees, (*b*) the shrubs or bushes beneath them, and (*c*) the herbaceous plants and ferns which carpet the ground. These light relationships are recognized by the farmer, who knows that he can grow beans and pumpkins advantageously with the corn. Many crops, such as tobacco and pineapples, are sometimes grown under the shade of cheesecloth or slats. Of course, these shading devices not only protect the plants from too intense sunlight, but they also protect against storms and conserve the water supply.

LABORATORY EXERCISES.

Exercise 1. Grow some seedlings in pots under the same conditions. When the plants are well above ground, put one-half in a place where the light is the same from all sides and the other half where the light comes from one side only. After two weeks compare the two lots. What differences do you observe? What conclusions can you draw from this experiment?

Exercise 2. Diagram the leaves of a dandelion or other acaulescent plant. What per cent. of the lower leaf surface is shaded by the upper leaves?

Exercise 3. Put thin slices of beet and some thin leaves (nasturtium or lettuce, *e.g.*) in a beaker of water containing a thermometer. Heat very slowly. At what temperature does the color escape from the beet cells? At what temperature do the leaves lose their turgor? Can it be restored if they are promptly replaced in cold water? Explain.

Exercise 4. Count out two lots of 100 seeds each of wheat or other grain. Weigh each lot and record the result. Dry one lot for several hours at 100 degrees C. Weigh again. Germinate the other lot, and after the plumules are well started, dry for same length of time as the first lot. Which lot has lost the greatest per cent. of its original weight? Why?

Exercise 5. Select half a dozen potatoes in which the sprouts have just started. Divide into two lots and put in a plate under a bell jar containing some moistened blotting paper. Put one lot in a well-lighted place, the other lot in a dark place for a few weeks and then compare them.

CHAPTER XXI

PLANT EVOLUTION

The Theory of Special Creation.—The rise of botanical science was comparatively slow. As long as Mother Nature supplied the human race with all its needs, there was no great incentive for the study of plant life or for effort to increase plant production. If we look into the history of the science, we find that much of the early progress was due to man's efforts to find plants of medicinal value. This study necessitated the classification of plants and step by step the study of the science advanced. As the science progressed, the students of botany gave more and more attention to the study of classification and eventually to the laws governing both plant and animal life. These questions were not new; they had been considered by the Greek philosophers 2000 years ago or more, but through all this long period of time very little attention was given to the study of living plants by educated men. The predominating idea concerning the universe, the earth and the life on it was what is now known as *The Theory of Special Creation.* This theory was based on a literal interpretation of the Book of Genesis. The sun, moon, earth and all the forms of life on the earth were the results of a series of Divine acts during a period of seven days. After this period of creation, the earth and all forms of life had remained practically unchanged. This idea of special creation was questioned from time to time by learned men, but no great progress was made until Charles Darwin advanced *The Theory of Natural Selection.*

Evolution.—From our previous studies we have learned that plants range from very small, simple organisms to very large, complex organisms. Most of them are absolutely dependent on sunlight for their existence, and all animal life is dependent on plant life. Therefore, plants must have appeared on the earth in advance of animal life. We have reason to believe that these first forms of plant life must have been very small and very simple in structure; in fact, they may have been simpler than any species of plant in existence at this time. We have reason to believe that other forms of plant life, possibly all forms, have been derived from these first forms of life. To accomplish this requires many changes through long periods of time. This modification of plant life is known as "organic evolution." It offers no satisfactory explanation as to the origin of the earth or the source of life, but by the study of the laws of nature, it attempts to explain the modification of plant and animal life through the long geological ages. This theory of organic evolution is exactly the reverse of the theory of special creation. It is a theory of gradual change and implies that the present forms of life are different from the original forms. It emphasizes not only the origin of life but the laws controlling life.

Geological Record.—Evolution is not restricted to living things. The inorganic, as well as the organic, is subject to great changes, due to the laws of nature.

The earth has undergone many and wonderful changes since its origin, and in fact these changes are going on at the present time. Earthquakes and volcanoes bring sudden changes, but water, frost, wind and other agencies are slowly but surely wearing down the mountain ranges, filling the valleys and modifying the face of the earth. What was once the surface may now be covered to great depths by rock, soil or water, and areas that were once covered with water may now be found at great elevations. Nature has left readable records of these great changes and among the most important of these records are the fossil remains of extinct plants and animals. A study of these fossil remains shows gradual changes in the forms of plant life on the earth. These changes have very generally been from lower to higher types, but there is an abundance of evidence that lower types may be derived from higher types (see page 273). Furthermore, the predominating forms of life have not always been the same. No doubt there must have been a period when the algæ were predominant. This was followed by the age of mosses and then the age of ferns. More recently the coniferous plants were most abundant, and this period was followed by the development of the flowering plants of the present.

Geographical Record.—The present distribution of plants over the face of the earth involves the study of ecology and plant geography to which we have already referred. The most important factors influencing the distribution of plants are water, temperature, soil, light, wind, mountain ranges, deserts, rivers, lakes, seas, animals and man; all of which have been discussed to a greater or less extent in the preceding chapters. The study of the relationship of plants to these environmental agencies has led to the grouping of plants that grow under the same conditions into societies, such as hydrophytic, mesophytic, xerophytic, alpine, prairie and numerous others of more or less importance. The grouping of plants into these societies has very little relation to the classification of plants in accordance with the natural system which will be discussed in Part III of this book.

Theories of Evolution.—It is very easy to point out similarities and differences between forms of life, both past and present, but the explanation of these similarities and differences presents many problems which have given rise to several theories of evolution. Although evolution was partially recognized by a few scholars during the periods of ancient and medieval history, it has made its greatest advance within the last century. These various theories and explanations can be studied to the best advantage in connection with the workers by whom they were advanced.

Fig. 107.—Lamarck.

Lamarck.—This very noted French naturalist (Fig. 107) advanced the theory of use and disuse in 1801. This theory assumed that the environment was constantly changing and that animals made certain efforts in accordance with desires which resulted in modifications. For example, the giraffe, by continued efforts to reach the foliage of the trees, gradually, through many generations, developed a long neck. Snakes, preferring to travel by gliding movements, had no very great need for legs and continued disuse led to their gradual disappearance. Since plants could not make conscious efforts, he assumed that they were unconsciously modified by the environmental factors. Of course, this theory depended on the assumption that the offspring would inherit characters acquired by the parents previous to the birth of the offspring. However, it is very generally believed that acquired characters are not inherited by either plants or animals. The next great step in the study of organic evolution was made by Charles Darwin.

Darwin.—This well-known English scientist (Fig. 108) advanced the theory of *Natural Selection* in 1859 in his book entitled *The Origin of Species.* He assumed that creation was a continuous evolutionary process and that the most important factor was natural selection. This theory was based on the idea that every individual plant and animal must be fitted to its environment and that it is in competition with other plants and animals. Very naturally those individuals that were best suited to their environment and able to compete with their rivals and enemies of various kinds would survive and produce offspring, while those that were not so favored by nature would perish, leaving few or no progeny. This theory involved variation, inheritance, struggle for existence and survival of the fittest.

FIG. 108.—Charles Darwin.

Individual variation is very generally recognized by all close observers of nature. No two individuals are exactly alike, although it may be very difficult to point out the differences. In fact, the leaves (Fig. 109) on the plant show more or less decided variations. Darwin believed that when these individual variations proved advantageous, the possessor would have more chance of surviving and producing offspring than the individual that did not possess them. He also believed that valuable variations were transmitted (or inherited) and intensified from generation to generation. Therefore, these gradual variations would eventually give rise to a race or species of individuals quite different from their ancestors.

Darwin's ideas involved the *struggle for existence* and the *survival of the fittest.* Plants must be fitted to their environment or perish; if there should be a pronounced change in the environment, such as a change in the water supply, it would be necessary for the plants to undergo corresponding changes or perish. Therefore, the great changes in the earth, involving elevation or subsidence of large areas, accompanied by changes in climate,

FIG. 109.—Variation in leaves from a single branch of a mulberry tree.

had necessitated changes in the forms of life on the earth. Furthermore, plants were in competition with each other; when a number of plants try to occupy the same area, the weaker individual and species must perish. Therefore, the plants were in a continuous struggle with both their environment and their rivals; and only the fittest would survive and perpetuate their kind.

Darwin's theories of evolution were met by opposition on the part of many people, especially the theologians, who believed that his theories eliminated Deity. In fact, Darwin's theories did not eliminate Deity, but they did emphasize the importance of natural laws. However, his theories were accepted by many scientists and eventually by educated people very generally. The principles of organic evolution as set forth by Darwin have had a more far-reaching influence than those of any other scientific worker. Darwin and his immediate followers were observers of nature rather than experimenters, but in a very few years there arose a school of workers who insisted on proving or disproving theories by experimental evidence. This method has now spread to practically all branches of the biological sciences.

FIG. 110.—Johann Gregor Mendel. (From Gager's Fundamentals of Botany.)

Mendel.—Johann Gregor Mendel (Fig. 110) is a name well known to the students of heredity in plant and animal life. He was an Austrian monk who was interested in the breeding of plants and worked out certain laws of heredity which bear his name. His results were published in an obscure publication about 1865 and did not attract attention until about 1900, when they were brought to light by Correns, DeVries and Tschermak. They have had a very decided influence on the study of evolution. Mendel's work was primarily with peas, in which he always studied the inheritance of two contrasting characters. Two plants with contrasting characters (such as long and short plants, smooth and wrinkled seeds, gray or brown seed coats, yellow or green cotyledons) were selected and cross-pollinated. The seeds were carefully collected and planted throughout a series of generations without further cross-pollination, the seeds of each individual plant being always kept separate. The results, very briefly stated, were as follows (Fig. 111): In the first generation (known as F_1 *generation*), all the offspring present but one of the two contrasting characters for which the parents were selected. Mendel designated this as the "dominant character" and the character that failed to appear as the "recessive character." These plants were self-pollinated and the F_2 generation grown. In the F_2 generation 75 per cent. of the plants presented the same character as the F_1 generation (*i.e.*, the dominant character), while 25 per cent. present the grandparent character which had failed to appear in the F_1 generation (*i.e.*, the recessive character). The 25 per cent. bearing the recessive character present this same character throughout succeeding generations. But if the 75 per cent. of the F_2 generation, which bear the dominant character, are self-pollinated and the seeds planted, it will be found that one-third of them (*i.e.*, 25 per cent. of the F_2 generation) produce the dominant character which will be perpetuated through succeeding generations. But the other two-thirds (*i.e.*, 50 per cent. of the F_2 generation) will produce plants with the characters as follows: 25 per cent. dominant, 50 per cent. mixed and 25 per cent. recessive. This is illustrated in the diagram (Fig. 111) in which we will use the square and circle as representing the two characters under consideration.

Briefly stated, Mendel's Law is as follows: There are two kinds of characters which do not blend but behave as separate units and are known as dominants and recessives. Although these characters do not blend, they reappear in the individuals of successive generations in the ratio of 25 per cent. with dominant characters, 25 per cent. with recessive characters and 50 per cent. with both characters. Those bearing dominant and recessive characters only will breed true, but those bearing both characters will produce offspring in which the characters will continue to reappear in the ratio of 25 : 50 : 25. These laws have formed the basis of much very valuable research of the past

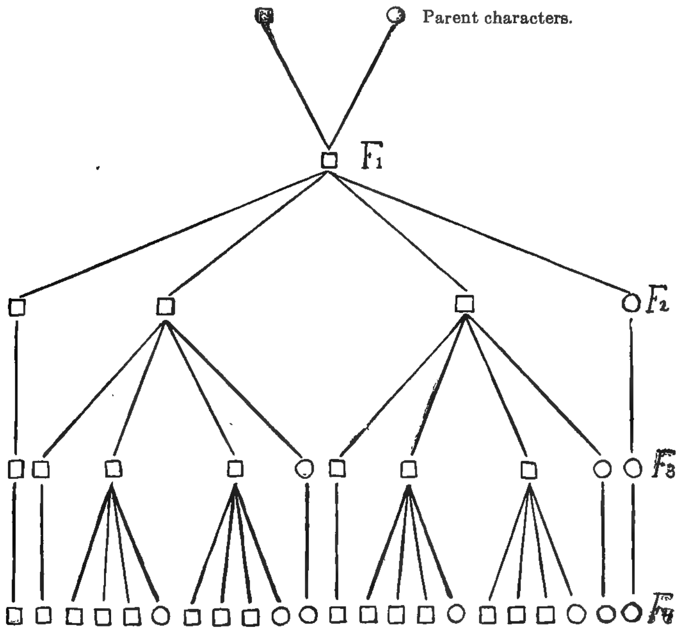

FIG. 111.—Diagram illustrating Mendelism.

two decades. They demonstrated the value of pedigree cultures in the study of heredity and enabled the experienced worker to predict and interpret results. They explain the reappearance of characters which had apparently been lost in one or more preceding generations.

These characters are believed to be carried in the chromosomes of the nuclei (see page 129) and may be briefly explained as follows: The nucleus contains chromatic material from both parents. When the cell divides, the maternal and paternal chromatin appear to organize separately and therefore each maintains its individuality in the offspring. Although the cells may receive an equal amount of chromatic material, they do not necessarily receive the same characters. Since the parents bear not two but a great many characters, the number of possible combinations are enormous. It has been demonstrated that more than 100 pairs of characters adhere more or less closely to the Mendelian Laws.

FIG. 112.—Hugo DeVries.

DeVries.—This well-known Dutch scientist (Fig. 112) extended and explained a great deal of the work of his predecessors. By growing pedigreed plants and studying them through many generations, he demonstrated that there were two kinds of variations, the continuous and discontinuous, and finally brought forth the *mutation theory.* The continuous variations are the very common but very slight variations which are very generally recognized by every one, such as those in size and color of the individual fruits from the same tree, of leaves from the same plant or of seeds from the same plant. The variations are within certain limits and it is doubted if any one of them gives rise to any well-defined type. The discontinuous variations are known as mutations; they arise suddenly, are well defined and persist in succeeding generations, thus giving rise to new types. It was formerly believed that many of the great number of varieties of our agricultural crops had originated by gradual variations, but it is now very generally believed that they are true mutants.

The mutation theory of DeVries does not contradict Darwin's theory of natural selection. Darwin believed that all kinds of variations could be inherited and that those that were useful to the plant would be intensified through succeeding generations, thus giving rise to new and distinct types. But, according to the DeVries theory, the mutants only possess the characters by which new types are established. However, it remains for natural selection to determine which of the mutants shall persist and which will be lost in the struggle for existence.

The cause of variations is as yet unexplained. Of course, plants will vary in size, vigor and many other characters as a result of amount of water, food, light, temperature and many other environmental factors, but these variations do not appear to be inherited. Mutations appear to be due to changes within the individual.

CHAPTER XXII

APPLICATIONS OF BOTANY

BOTANY is one of the very oldest of the *sciences* and treats of plant life, upon which all other forms of life depend; in fact, it may be called the most fundamental of all sciences. It would be extremely difficult to tell the beginnings of this science; was it when the human race took the first step in agriculture, or did it begin with the commerce in plant products, or did it begin at some later period when some individual began the study of plants for some definite purpose? Primitive agriculture is practiced by the savage and partly civilized tribes of men throughout the earth. The ancient agriculture of the old world reached its highest development in the fertile valleys of southern Asia, in the Valley of the Nile and in southern Europe. When America was discovered, its highest development of agriculture was found in Mexico, Central America and the Andes regions of South America. The advancement of agriculture necessitated that wandering tribes cease their nomadic life and their dependence on natural production and give more or less of their attention and time to increasing the production of plant life. In many parts of the world the growing of crops was associated with religious activities and special festival seasons were designated for celebrating seed-time and harvest.

With the advance of civilization, man gave more and more time to the study of useful plants. The first great and important steps in the study of botany began with the search for medicinal plants. The early works on botany were peculiar mixtures of studies in botany and philosophy. Many of the early botanists and some of the very recent ones were practitioners of medicine. But in time botany passed out of the hands of the medical profession and is now recognized as fundamentally associated with agriculture. Unfortunately, it has been divided into branches bearing names so distinct that many people fail to recognize them as divisions of botany. The most important of these divisions of applied botany are agronomy, horticulture, forestry, plant breeding, bacteriology, plant pathology and pharmaceutical botany.

Agronomy is the study of field crops, more especially of cereals and forage plants, and involves not only the study of the plants but also the study of soils, fertilizers, culture and many other factors. It must be closely correlated with plant breeding, soil bacteriology and plant pathology. It also involves a knowledge of plant physiology, plant ecology and plant geography; no great advancement can be made in the introduction and growing of new plants without a knowledge of the conditions under which they are grown.

Horticulture is subdivided into three branches as follows: (*a*) *Pomology,* which deals with the growing of fruits. It is a very important and highly developed industry. (*b*) *Olericulture,* which deals with the growing of vegetable and truck crops, is also an extremely important and highly developed industry. (*c*) *Floriculture,* which deals with the growing of ornamentals, is also an extremely important industry. It is especially highly developed in the immediate vicinities of our large cities. It involves the growing of both indoor and outdoor ornamentals and landscape gardening, and the study of varieties, plant food and culture. They are all closely associated with plant breeding, soil bacteriology and plant pathology and involve a knowledge of physiology, ecology and geography.

Forestry is very generally recognized as an independent subject, but it has to do with plants and must be considered a botanical subject. It has to do with the preservation of our

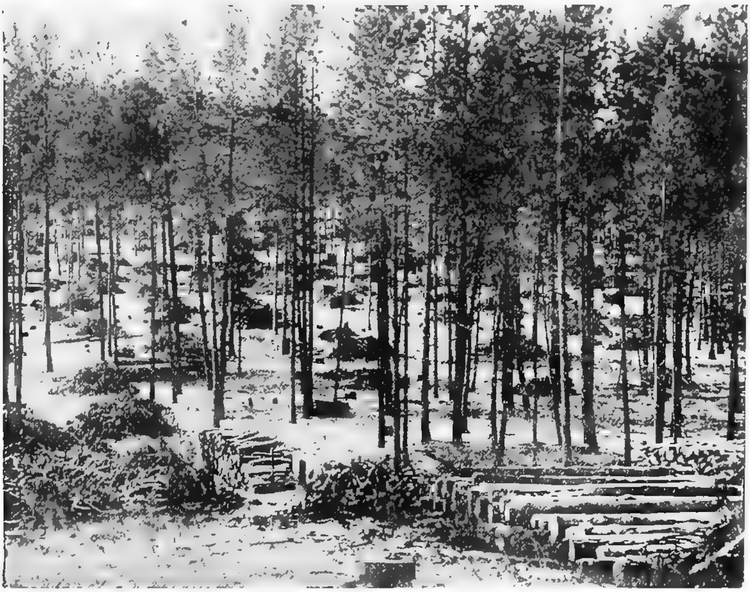

Fig. 113.—Modern forestry methods provide for perpetual crops of lumber and other forest products. (U. S. D. A.)

natural forests, the planting of new forests, the control and protection of forest areas and the utilization of forest products in the industries. It is a very old subject in Europe, where the people recognized centuries ago the necessity of a conservation of their natural resources. It is a comparatively new subject in America, but is now well established and recognized (Figs. 113 and 114). The United States Government has 151 national forest reserves, comprising 174,261,393 acres of land, and employs 3500 men. Most of the states also own forest reserves and employ professional foresters, and many cities also employ professional foresters to look after their park and street trees.

Plant breeding works for the improvement of existing varieties and the production of new varieties. Previous to the recog-

Fig. 114.—Denuded of forest growth by ruthless cutting and fires. A barren rocky waste is left, unsuited to other agricultural crops. (U. S. D. A.)

nition of the work of Mendel and DeVries, it consisted almost entirely in the aimless selection of desirable individuals and the progress was slow. However, the great majority of our valuable agricultural varieties were probably obtained in this manner. The ultimate object of plant breeding is to increase the yield, improve the quality of the product, to secure new varieties, or to develop resistance to drouth or disease. It involves selection, hybridization and a thorough knowledge of the laws of evolution as worked out by Darwin, Mendel, DeVries and other more recent students of the subject.

Bacteriology dates from the work of the great French scientist, Pasteur (Fig. 115). It involves the study of the very minute organisms, which are probably the lowest of the fungi. Some of these organisms are extremely important factors in soil fertility and therefore it is very closely associated with agriculture; other organisms are the cause of diseases of man and beast and therefore it is closely associated with the study and practice of medicine; other organisms are the cause of diseases of plants and therefore it is closely associated with the study of plant pathology; while still others are of importance in the manufacturing industries.

Fig. 115.—Pasteur.

Plant pathology deals with the causes and treatments of plant diseases. For many years it was studied by two entirely different groups of workers, the mycologist, who was interested primarily in the causal organism, and by the grower, who was interested in the protection of his crops. Little progress was made under these conditions, but finally the subject was taken up in a more comprehensive manner by the botanists and is now recognized as one of the most important branches of botany. It involves a careful study of the organisms causing the diseases, their effect on the host plant and the methods of eradication or control. The object of plant pathology is primarily the increase of plant production by the protection of valuable plants from their enemies. It is very closely correlated with plant physiology, agronomy, horticulture and forestry.

Pharmaceutical botany has to do with the growing and utilization of drug plants. It will be readily seen that it is closely associated with taxonomic botany, crop production, chemistry and the practice of medicine.

AGRICULTURAL PLANTS

Agricultural plants are those that mankind has selected because of their value and because the needs of mankind could be supplied to better advantage by growing them than by depending on the wild product. The beginnings of agriculture are so remote in history and so shrouded in tradition and superstition that our knowledge is very imperfect. Ancient and savage people attributed the origin of many plants to some particular deity or to some great ruler, and these traditions were preserved in their earliest literature. *Ceres* was the goddess of agriculture, and the grains are known as cereals; *Pomona* was the goddess of fruits, and apples, pears and quinces are still known as the pomaceous fruits.

Agriculture probably began in the gathering of fruits, and this was followed by the scattering of seeds as a religious service, with the expectation that the gods would give an abundant harvest. Of course, early agriculture made its greatest progress among those people who were inclined to form settlements. Southern Asia and the Mediterranean regions were the scenes of the early development of agriculture in the eastern hemisphere. In fact, the earliest agriculture may be said to have originated in southwestern Asia and to have moved westward along the shore of the Mediterranean and thence into other parts of the world, although agriculture is very ancient in China, Egypt and India. Agriculture was practiced in southern Europe at a very early date, but received a great impetus from the Aryan migrations from Asia about 2500 or 2000 years B.C. (Fig. 116).

Ancient Agriculture in America.—Agriculture in the western hemisphere is not as old as in the eastern hemisphere, but

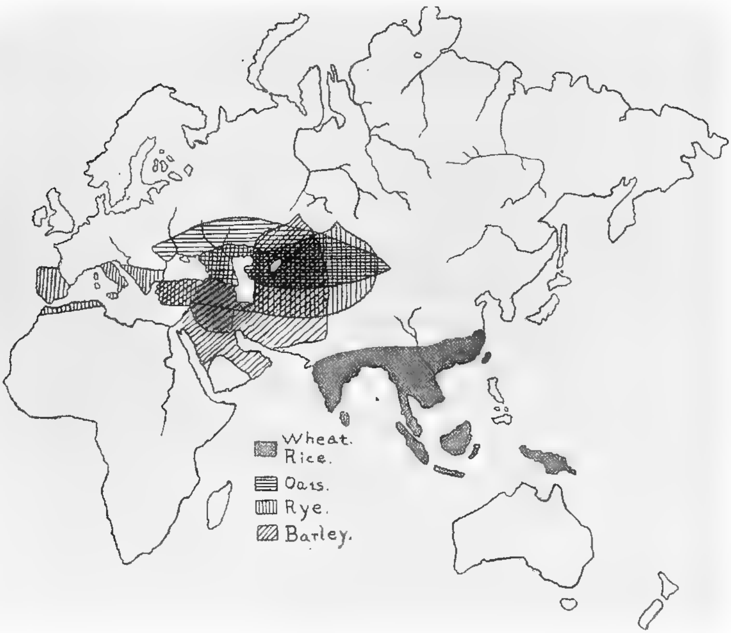

FIG. 116.—Map showing the origin of some of our most important grain crops.

was practiced by aborigines long before the coming of the white man. It reached its highest development in Mexico, Central America, Peru and adjacent regions. We are indebted to America for many of our most important agricultural plants, such as corn, potatoes, tomatoes, tobacco, cacao, sweet potatoes and many others.

Plant Improvement.—The firm establishment of agriculture was naturally followed by the selection of the best plants and improvement in methods. Plants tend to vary; in some cases the variations being very pronounced. Therefore, the most intelligent and progressive peoples selected the most desirable plants and studied methods for their perpetuation. So little by little, at first very slowly, but later very rapidly, the science and art of agriculture advanced to its present high standard.

A careful study will show that there were three great centers which may be considered the homes of agriculture. They are the Mediterranean center, the Oriental center and the American center. The first gave rise to wheat, oats, barley, rye, almond, pea, bean, asparagus, onion, parsnip, turnip, carrot, cabbage, celery, lettuce, spinach, cucumber, muskmelon, watermelon, egg-plant, apple, pear, quince, plum, cherry, European grape, lemon, date, fig, olive and many other plants.

The second center gave us the rice, orange, peach, banana and sugar cane.

The third gave the world Indian corn, potato, sweet potato, tomato, peanut, kidney bean, lima bean, pumpkin, pineapple, cacao and cocoanut and many other valuable plants.

PART III

CLASSIFICATION AND ECONOMICS

PLANTS are so abundant and the number of different kinds is so great that some system of classification is necessary in order to conduct our studies in the most satisfactory manner. Furthermore, it is necessary that this classification shall be the same throughout the world, so that students of botany may work in harmony. The economic plants are distributed throughout the entire plant kingdom, but, of course, the great majority of them are to be found among the flowering plants.

CHAPTER XXIII

PRINCIPLES OF CLASSIFICATION

Many classifications have been suggested; each was used for a time and then gave way to another. These early classifications were "artificial," but in the course of time we have developed what we now call a "natural system." It is the product of the Darwinian theory of "natural selection" and is based primarily on phylogenetic relationships. *Phylogeny* is the term used to indicate the origin of a plant or animal from some previous form of plant or animal life. It necessitates a comparative study of the form, arrangement and structure of the organs of the plant or animal. Since the flowers are much more constant in character than the vegetative organs of the plant, they are of much greater importance in classification than the other organs. For example, the bean and the locust tree are very different in size and form, yet the reproductive organs show striking resemblances which lead to their being placed in the same family. The fruit of the apple and peach are quite different, but the study of the entire flower indicates a very close relationship.

Plants of the same kind are said to belong to the same species. Similar species are grouped into a genus. The generic and specific names combined constitute the scientific name of the plant. For example, all oak trees belong to the genus *Quercus.* The white oak is *Quercus alba;* the scarlet oak is *Q. coccinea;* the bur oak is *Q. macrocarpa;* the black oak is *Q. nigra;* the pin oak is *Q. palustris,* and the red oak is *Q. rubra.* This is known as the binominal system and was brought into general use by the work of the celebrated naturalist, Linnæus (Fig. 117).

In this same manner the genera which show resemblances are collected into families, the families into orders and the orders into classes. Although these are the most important groups, other divisions are sometimes made for convenience. Although the species may be considered the final group, yet we find many variations which sometimes necessitate smaller groups known as varieties. This is especially true of cultivated plants, and the commercial varieties of some species are numerous.

The specific name usually indicates some character of the plant to which it is attached, *i.e., vulgaris* = common, *nigra* = black and *rubra* = red. The Latin generic names are always written in the nominative case. The family names usually end in *aceæ*. The order names always end in *ales*. The class names usually end in *ineæ* or *eæ*. The division names end in *phyta* or *phyte*.

FIG. 117.—Linnæus.

The plant kingdom as a whole may be divided into four large groups or divisions as follows:

I. *Thallophyta,* which includes the algæ and fungi (page 260).

II. *Bryophyta,* which includes the liverworts and mosses (page 289).

III. *Pteridophyta,* which includes the ferns and related plants (page 297).

IV. *Spermatophyta,* which includes all seed-producing plants (page 303).

The *Spermatophyta* are divided into two groups, the *Gymnospermæ* (such as the pines, spruce, etc.); which produce seeds but no flowers and are mostly evergreens, and the *Angiospermæ,* which include the higher seed-bearing plants or true flowering plants.

The *Angiospermæ* are divided into *Monocotyledons,* in which the embryo has but one cotyledon or primary leaf, and the *Dicotyledons,* in which the embryo has two cotyledons (see page 304). Since the seeds of many plants are so very small, it is frequently desirable to use other characters. With some few exceptions, the following characters may be relied upon in grouping plants with reference to these two divisions. The monocotyledonous plants have endogenous stem (see page 304), parallel-veined leaves and the parts of the flower arranged in circles of three each. The dicotyledonous plants have exogenous stems (see page 304), net-veined leaves and the parts of the flower in circles of four, five or some other multiple.

CHAPTER XXIV

THALLOPHYTES

THE *Thallophytes* are the lowest of the four great divisions of plants. The term means "thallus plants," which are plants with little or no differentiation of vegetative organs; *i.e.,* there is no definite differentiation into true roots, stems and leaves. However, thallus bodies are found in the other groups of plants. Therefore, the thallus structure does not separate this group of plants definitely from the other groups. The Thallophytes are the lowest and simplest forms of plant life. In order to appreciate the evolutionary development of the plant kingdom, it is desirable to begin with these lower forms and follow the origin and development of the organs throughout the higher groups. Our knowledge of this group is not sufficient to enable us to make a very satisfactory classification, but the following is very generally accepted.

Thallophytes
- 1. Algæ. (Chlorophyll-bearing plants.)
  - 1. Cyanophyceæ. (Blue green algæ.)
  - 2. Chlorophyceæ (Green algæ.)
  - 3. Phæophyceæ.) (Brown algæ.)
  - 4. Rhodophyceæ. (Red algæ.)
- 2. Fungi. (Non-chlorophyll bearing plants.)
  - 1. Myxomycetes. (Slime molds.)
  - 2. Schizomyces. (Bacteria or fission fungi.)
  - 3. Phycomycetes. (Algal fungi.)
  - 4. Ascomycetes. (Sac fungi.)
  - 5. Basidiomycetes. (Basidial fungi.)

The *Algæ* are uni- or multi-cellular, chlorophyll-bearing thallus plants. They are mostly aquatic plants and are found in nearly every stream, pond, lake and sea throughout the world and in waters ranging in temperature from near the boiling point to the waters of the polar regions. A comparatively few species live on wet soil and rocks and a very few live on the bark of trees and in other places where the conditions are very dry for a considerable part of the time. Since they contain chlorophyll they must receive sunlight. They are of little direct economic importance. Some few are used for food, especially those growing along the coast of Japan; others have been used as a source of potassium, especially the very large marine forms of the American Pacific Coast; they are also an important source of iodine and a few other chemicals. However, when we take into consideration that they form one of the important sources of food, either directly or indirectly, for fishes and other aquatic animal life, we realize that it is extremely difficult to appreciate their true value. While fishes may not use the algæ directly to any great extent, they feed on other animals which have fed on the algæ. The young of most species of fish feed entirely on micro-organisms, both plant and animal. But the algæ are interesting to us from another and entirely different viewpoint. It is very evident that algæ or some very similar plants must have been the first forms to appear on the earth and that all other forms of life must have been derived from them. Therefore, a study of the algæ is very important in order to gain an understanding of organic evolution.

The *Cyanophyceæ* or *Schizophyceæ* (Fig. 118) are the "blue-green" or "fission algæ" and are characterized by the blue-green color due to a combination of phycocyanin and chlorophyll and to the fact that they reproduce by simple cell division. They are the simplest known species of the algæ, are microscopic in size, although they frequently form very conspicuous masses, and are very widely distributed throughout the earth. They are mostly aquatic and live in water ranging in temperature from near the boiling point to that of the arctic regions. Some species live on wet soil and rocks and others, known as *endophytes,* live within cavities of some of the higher plants, especially the liverworts and ferns. They are sometimes so abundant as to produce offensive odors when decaying, and have sometimes given trouble by accumulating in great quantities in the reservoirs supplying the water to large cities.

They are always unicellular, but in many cases are held together in very definite colonies. Each cell (with the exception of the *heterocysts*) has the power of performing all the life functions of a living plant and of producing a new colony. They are always surrounded with a more or less prominent gelatinous substance which is secreted by them and is of importance in holding them together. In most species the nucleus and cytoplasm are not well defined. There are no chloroplasts and the coloring matter is diffused throughout the cell. They always reproduce by simple fission and so far as known there is no other method of reproduction. Some of the most important genera are *Glœocapsa, Oscillatoria, Nostoc, Rivularia* and *Stigonema.*

The genus *Glœocopsa* (Fig. 118, *a*) is composed of unicellular algæ, which may be found on wet soil, stones or wood. Each individual plant (*i.e.,* cell) is more or less spherical, bluish-green in color and surrounded by a clear jelly-like substance. It reproduces by dividing into two daughter cells or plants which separate and divide again. Two or even four cells or plants frequently cling together for some time before separating.

The genus *Oscillatoria* (Fig. 119, *b*) is composed of filamentous species which may be found on wet soil, stones or wood or in shallow water. They frequently become detached and float on the surface as scum masses. Each filament consists of disc-shaped cells which are attached to each other by their flat surfaces. Although attached, there is no division of labor, each cell performing all the functions of an individual plant. Each filament is surrounded by a thin jelly-like layer and has the power of locomotion; it sways back and forth or moves in either direction. They reproduce by cell divisions at right angles to the long axis; the filaments break into shorter filaments in which the cells continue to divide.

The genus *Nostoc* (Fig. 118, *c*) is found on wet soil and rocks and in pools and streams. It consists of strings of spherical cells resembling strings of beads and the whole is embedded in a thick mass of jelly-like substance. They reproduce in the same manner as the *Oscillatoria.* Scattered along the filaments will be found cells which are somewhat larger than the others. They are thick-walled, have lost their contents and are known as *heterocysts.* The intervening chains of cells are known as *hormogonia* and appear to be anchored by the heterocysts; they occasionally break loose, wriggle out through the jelly and establish new colonies.

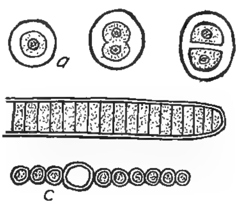

FIG. 118.—Cyanophyceæ; (*a*) Glœocapsæ, (*b*) Oscillatoria, (*c*) Nostoc.

The genus *Rivularia* is made up of filamentous, colonial species. The basal cell of each filament is a heterocyst, and the succeeding cells decrease in size, thus producing a whip-like colony.

The genus *Stigonema* consists of species in which the filaments branch. The branches originate as lateral outgrowths from individual cells.

The *Chlorophyceæ* or true green algæ are characterized by their green color, which is due to chlorophyll. They are widely distributed throughout the world in streams, ponds, lakes and seas, but are most abundant in the fresh waters. They range from microscopic, unicellular, to visible, multicellular forms, some of which frequently form very conspicuous masses. The protoplasmic contents of the cells are highly organized and chloroplasts are always present in the active cells. Reproduction is (*a*) by simple cell division, (*b*) by free swimming zoöspores, each capable of producing a new plant, (*c*) by *gametes* or sex cells which unite (usually in pairs) before the formation of new plants and (*d*) by the formation of well-defined sex organs (*antheridium* and *oögonium*) containing highly developed gametes (*sperms* and *oöspores*). The *Chlorophyceæ* can be divided into the following orders:

1. *Volvocales*—unicellular, single or colonial, usually motile species (page 264).

2. *Protococcales*—unicellular, colonial, non-motile species (page 266).

3. *Confervales*—multicellular, simple or branched filaments or flat branched filaments or flat thallus structures; reproduction by non-sexual cells or by gametes (page 267).

4. *Siphonales*—usually unicellular but often multinuclear, filamentous species, sometimes branched; reproduction by well-defined organs (page 268).

5. *Conjugales*—unicellular species or multicellular species; reproduction by conjugation (page 269).

6. *Charales*—a group whose place in the plant kingdom is questioned (page 271).

The order *Volvocales* is composed of unicellular and colonial forms, which are usually ciliate and motile and therefore have these characters in common with one of the groups of lower unicellular animals known as *Flagellates.* Among the most common genera are *Chlamydomonas, Sphærella, Pandorina, Eudorina* and *Volvox.*

Chlamydomonas (Fig. 119, *a–d*) and *Sphærella* are unicellular forms which have the power of locomotion by means of cilia. This power of locomotion is so highly developed that these species might very readily be mistaken for animals, if it were not for the fact that they contain chlorophyll and perform the same physiological functions as other chlorophyll-bearing plants. Each individual has a red spot known as the "eye spot," which is supposed to be sensitive to light. This red pigment is sometimes so abundant as to give pools of water a reddish tinge. The so-called "red snow" of the arctic regions is in reality due to masses of algæ belonging to this group in which this red pigment is very highly developed. The individual cells eventually lose the cilia and become dormant. During this period the contents divide into two, four or more cells, which take the form of the motile parent and escape as zoöspores. They increase in size and the process may be repeated indefinitely. Some individuals produce many very small zoöspores, which unite in pairs to form new plants. They are called *gametes* (sex cells) and since they are all alike, they are said to be *isogamous.* This union or fusion (conjugation) of sex cells is called *fertilization,* and the resulting cell is a *zygospore* or *zygote.*

Pandorina (Fig. 119, *e*) is a colony usually composed of sixteen cells, each of which is of the same general character as *Chlamydomonas* and *Sphærella.* The only important difference is that they hold together in groups by means of a gelatinous substance, and that each cell has the power of producing a new colony of sixteen cells. They produce gametes which are more or less variable in size and motility. However, they fuse without regard to either of these characters and, therefore, must be regarded as isogamous.

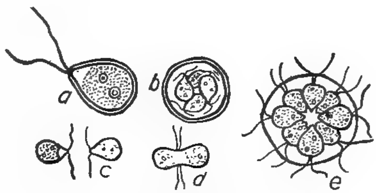

FIG. 119.—(*a* to *d*) Chlamydomonas; (*e*) Pandorina.

Eudorina is a larger colony than *Pandorina* and differs from it in that the gametes are *heterogamous; i.e.,* of two kinds, large and small. The large gametes may be considered as female or *egg* cells, while the small cells may be considered as male or *sperm* cells. The sperms unite with the eggs (*oöspheres*) to form *oöspores,* which in turn give rise to new colonies.

Volvox is the highest type of the motile forms. It consists of many cells arranged so as to form a hollow sphere and held together by a gelatinous substance. The entire colony may be large enough to be visible to the naked eye. Each cell is of the same general character and the cilia project outward. They are connected by cytoplasmic strands. The reproduction may be non-sexual or sexual. In the former case a cell becomes enlarged, passes into the center of the sphere and develops into a new colony. In the latter case certain cells become enlarged and develop into female gametes or oöspheres; while certain other cells produce numerous motile, male gametes or sperms. Both female and male gametes escape into the inner part of the sphere, fuse and form oöspores, which are capable of producing new colonies.

Therefore, it will be readily seen that the unicellular forms belonging to this order are fully developed plants performing all the functions of a plant, regardless of size or differentiation. In some of the colonial forms each cell retains all its functions, while in others there is a division of labor in which some of the cells perform the duties of reproduction. It will also be readily seen that we find in this order several stages in the evolution of reproduction: (1) the formation of new individuals by a sexual cell division, (2) the formation of new individuals by the union of like sex cells or gametes, (3) the formation of new individuals by the union of unlike cells or gametes, (4) the formation of colonies, and (5) the division of labor.

The order *Protococcales* is composed of unicellular and multicellular species in which the vegetative cells do not possess cilia and are not motile, but the reproduction is practically the same as in the *Volvocales*. They are mostly aquatic, but some of them live on damp soil, stones and the bark of trees. Some are endophytic, living in the intercellular spaces of other plants; while others are parasitized by fungi, thus forming the plants known as lichens (see page 281). Some of the most common genera are: *Pleurococcus, Scenedesmus, Pediastrum, Hydrodictyon* and *Euglena*.

Pleurococcus is a very simple, unicellular form, which forms a green coating over wet flower pots, walls, soil and trees. The cells are more or less spherical and non-motile. The protoplasmic content is highly developed. It reproduces by simple fission only.

Scenedesmus (Fig. 120, *a*) is a fresh-water form, consisting usually of four cells arranged in a row. Each cell is capable of forming a new colony. There are no gametes.

Pediastrum (Fig. 120, *b*) consists of four, eight, sixteen or occasionally of thirty-two cells arranged in a plate-like colony. It reproduces by both zoöspores and gametes.

Hydrodictyon has the cells arranged in the form of a net and is known as the water-net. It reproduces by means of zoöspores and isogamous gametes.

The *Euglena* belongs to a group of algæ known as *Flagellates* which are somewhat anomalous. They differ from certain unicellular animals primarily by possessing chlorophyll. They are aquatic and move by means of one or two (occasionally more) cilia. The protoplasm is either naked or covered with a cell wall which usually resembles the cell wall of the animal (*i.e.*, non-cellulose). They also have a contractile movement and take in food in a manner similar to the related forms of animal life. They reproduce by cell division. They have chlorophyll and form-resting spores very similar to many of the related plants.

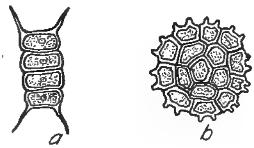

FIG. 120.—(*a*) Scenedesmus; (*b*) Pediastrum.

The order *Confervales* consists of multicellular, simple or branched filaments, or flat thallus structures. Reproduction is both non-sexual and sexual and the zoöspores are ciliate. The sexual reproduction ranges from isogamy to heterogamy with distinct oögonia and antheridia. The zygospores may produce new plants directly or zoöspores, but the oöspores always produce zoöspores. Some of the most common genera are *Ulothrix, Cladophora, Œdogonium* and *Coleochæte.*

Ulothrix (Fig. 121, *a–e*) is a very common filamentous, isogamous form. The cell at one end of the filament is differentiated into a holdfast by which the plant is attached. The other cells are in the form of short cylinders and uninucleate. Any cells may produce zoöspores, which resemble the cells of the Volvocales. The large zoöspores are four-ciliate and after swimming for a time come to rest and grow into new filaments. Sometimes very small biciliate zoöspores (gametes) are formed which fuse and produce zygospores, which in turn give rise to a generation of zoöspores which grow into new plants.

Œdogonium (Fig. 122, *f–h*) is a very common filamentous heterogamous form. The plants are anchored to stones or sticks and each cell is uninucleate. Some cells produce large, usually solitary, zoöspores bearing a crown of cilia and having the power to grow into new plants. Other cells form large oögonia, each containing a single egg or oösphere, while still other small cells produce one or more sperms. The sperms escape and swim,

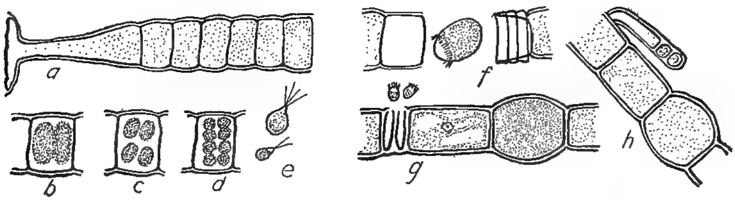

FIG. 121.—(*a* to *e*) Ulothrix; (*f* to *h*) Œdogonium.

some of them reaching the oögonia, which they enter through a small opening and fuse with the egg or oösphere.

In certain other species the oögonia and antheridia may be produced on different filaments and are therefore *diœcious*. The female plants are large and are produced from large zoöspores. The male plants are small and are produced from small zoöspores (androspores), which are somewhat larger than sperms. These small male plants are frequently attached to the female plants and the terminal cells develop into antheridia.

Coleochæte is a small plate-like body composed of many cells and is usually found attached to water plants. Although small, it has a comparatively complex structure. It reproduces by means of zoöspores and heterogamous gametes.

The order *Siphonales* is composed of species which are filamentous and with few or no septa. Although they may be considered unicellular they are multinuclear. A plant body of this type is known as a *cœnocyte.* The sexual reproduction ranges from isogamy to heterogamy with highly developed oögonia and antheridia. Among the most important genera are *Botrydium* and *Vaucheria.*

Botrydium is a very simple form. It consists of a balloon-shaped body resting on wet soil into which it sends numerous processes. It is unicellular, multinuclear and produces numerous isogamous gametes.

Vaucheria (Fig. 122, *a*) is a simple or branched, filamentous, unicellular but multinuclear plant living on damp soil or in more or less stagnant water. Large multinucleate zoöspores are pro-

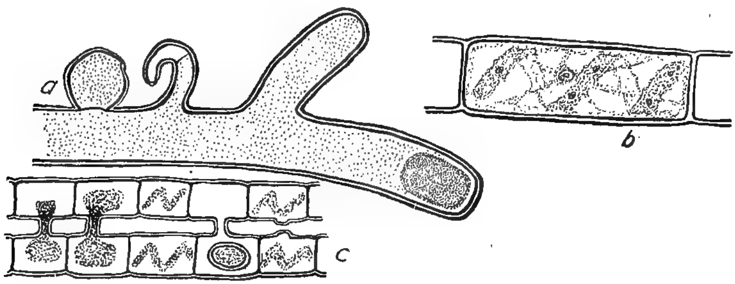

FIG. 122.—(*a*) Vaucheria; (*b*) Spirogyra; (*c*) conjugating Spirogyra.

duced at the tips of the branches; they are covered with paired cilia, one pair to each nucleus, and are in fact compound zoöspores. They grow directly into new plants.

The sexual reproductive organs are highly developed for the production of gametes but show considerable variation. They are produced laterally and may be united or independent. The oögonium is large and contains a single large egg or oösphere. The antheridium is small and curved, with the apical cell producing the sperms. The sperms escape and swim, one of them finally penetrating an oögonium through an opening and uniting with the oösphere to form an oöspore, which germinates directly into a new plant.

The *Conjugales* range from unicellular plants to multicellular filaments. There is no non-sexual reproduction other than simple cell division and no motile cells. Sexual reproduction is by conjugation of the protoplasts, usually through conjugating tube structures. *Desmids* and *Spirogyra* are the most common forms.

Spirogyra (Fig. 122, *a–b*) is a multicellular, filamentous plant characterized by the very prominent spiral, band-like chloroplasts. Each cell is uninuclear and capable of division. In the sexual reproduction small tubes are formed from the cells of two adjacent filaments which finally meet and fuse (*conjugation*). The contents of the cells of one tube pass into the cells of the other and the result is the formation of large resting spores, known as *zygospores*. Sometimes cells resembling zygospores are formed without conjugation; this process is known as *parthenogenesis*.

Desmids is a term used to designate a great number of minute, unicellular floating fresh-water plants of great beauty. The cell is organized into symmetrical halves and the reproduction is the same as in the *Spirogyra*.

The *Phæophyceæ* or brown algæ are confined to the salt waters and are most abundant in relatively cold regions. Many of them are very large, and in fact the longest known plants belong to this group. They are especially abundant on our Pacific Coast and include the kelps and other large forms. They have been used to some extent as a source of potassium for fertilizers. They are well worthy of an extensive discussion, which cannot be given in a book of this kind.

The *Rhodophyceæ* or red algæ are mostly salt-water forms and are most abundant in the warm waters. They range from very small forms to species of considerable size, but are not nearly so large as the brown algæ. Some of them are very complex in structure and method of reproduction and are of considerable importance in the study of the evolution of plant life. Some few of the gelatinous species are of value as foods.

Anomalous Algæ.—There are two groups of algæ that do not appear to fit into any of the recognized groups. They are the *Diatoms* and the *Stoneworts*.

The *Diatoms* (Fig. 123) are unicellular forms that are sometimes classed with the conjugales because of their method of reproduction and sometimes with the *Phæophyceæ* because of their brown color. They are very small and very abundant in fresh and salt water and on wet soil and also in both cold and hot waters. They are extremely variable in shape and the cell wall becomes impregnated with silica, thus forming a very hard and durable shell. This shell consists of two parts, the one fitting over the other very similar to the lid on a pill box. They have very delicate markings which are characteristic of the species. The fossil shells are often found in very great abundance, sometimes forming very large deposits of silicious earth. This diatomaceous earth is an important article of commerce and is used extensively in the manufacture of dynamite and scouring soaps.

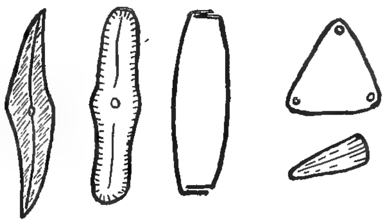

FIG. 123.—Common types of Diatoms.

Some diatoms are attached, while others are free swimming. The power of locomotion is probably due to very delicate strands of protoplasm which project through small openings in the shell. Non-sexual reproduction is by cell division, one half of each new cell taking one-half the old shell and forming a new half shell which fits into the old one. Of course, the daughter plant cannot be larger than the parent shell and therefore we have the development of a number of small individuals. However, after a certain amount of reduction, a cell may lose its shells and become an *auxospore* (*i.e.*, an enlarged spore of naked protoplasm) which has the power of growing and producing new shells of full size. Sometimes the protoplasm of two individuals unites (conjugates) to form an auxospore. Sometimes four daughter cells are formed from two cells and unite in pairs.

The *Stoneworts* (*Charales*) are sometimes classified as the highest group of the algæ, but some students of botany consider them as being entirely different from the algæ. They grow in great abundance in fresh and brackish waters and consist of stem-like structures with nodes and internodes. These stems are frequently incrusted with calcium carbonate and have whorls of branch-like leaves at the nodes. They reproduce by very highly developed antheridia and oögonia.

LABORATORY EXERCISES.

Exercise 1. Examine specimens of Glœocapsa. Note character of cells, jelly-like capsule and cell division.

Exercise 2. Examine specimens of Oscillatoria. Note character of cells, jelly-like covering and locomotion.

Exercise 3. Examine mass of Nostoc as found growing. Examine under microscope and note shape and arrangement of cells and heterocysts.

Exercise 4. Examine such of the following or similar organisms as may be avaiable: Chlamydomonas, Sphærella, Eudorina and Volvox.

Exercise 5. Examine such of the following or similar organisms as may be available: Pleurococcus, Scenedesmus, Pediastrum, Hydrodictyon and Euglena.

Exercise 6. Examine specimens of Ulothrix and Œdogonium and note as many points in structure and life history as possible. Note especially the basal or holdfast cells, chloroplasts, nucleus and reproductive organs.

Exercise 7. Examine specimens of Vaucheria and note as many points in structure and life history as possible. Note especially the location and character of the sex organs.

Exercise 8. Examine specimens of Spirogyra and Desmids. Note as many points in structure and life history as possible.

Exercise 9. Examine a number of specimens of Diatoms.

CHAPTER XXV

THALLOPHYTES (Continued)—FUNGI

The fungi are very similar to the algæ in structure and methods of reproduction, but since they do not possess chlorophyll they are very different physiologically; that is, they are unable to manufacture their own food and, like the animals, must depend upon the green or chlorophyll-bearing plants. They range from the extremely small, unicellular, microscopic forms to the very large fleshy forms. They may be divided on basis of habit into *parasites* and *saprophytes;* the parasitic species feeding on living plants or animals, while the saprophytic species live on decaying organic matter. Their strong resemblance to the algæ indicates that they are probably the descendants of the algæ. In fact, it is a true case of retrogressive evolution. Many of them are the causes of diseases of plants and some of them are very destructive to our farm crops and natural forests and the cause of very heavy losses. We have already called attention to the five most important divisions (page 260): *Myxomycetes, Schizomycetes, Phycomycetes, Ascomycetes* and *Basidiomycetes.* The last three may be considered the true fungi. There is still another—the *fungi imperfecti*—including a very large number of species, of which the life history is not definitely known or which do not coincide with the other divisions.

Myxomycetes or *Mycetozoa.*—This group of organisms is commonly known as "slime molds" and possesses characters of both plants and animals (Fig. 124). The plant body is a naked mass of protoplasm known as a *plasmodium.* It travels very slowly by a creeping motion and lives very much like a large amœba (very simple form of animal life) by means of streaming projections of the protoplasm. It pushes over and encloses many small organisms, which it digests.

In reproduction it forms stationary bodies of definite form which resemble fungi. These structures are characteristic of the different species and are known as *sporangia.* They bear the spores which under favorable conditions of warmth and moisture give rise to ciliate, unicellular, animal-like cells which fuse and form a new multinuclear plasmodium.

Most of the species belonging to this division are saprophytic, but some few are the causes of diseases of other plants. The club root of the cabbage, a very important and destructive disease, is due to one of these species.

The *Schizomycetes* are the "fission fungi" or "bacteria." They are extremely small, unicellular organisms, and are capable of multiplying very rapidly. They are the smallest known forms of life. They are very similar in structure and life history to the *Cyanophyceæ* (page 261), but they do not contain the coloring materials. Some of them are saprophytes and others are parasites. There is an enormous number of species and we see the results of their activities on every hand. They live on or in the food supply which they take in through any part of the cell wall by means of absorption. However, the food must first undergo a change as a result of the action of enzymes which are secreted by the organism. Some require air and are known as *aërobic forms,* while others thrive best without air and are known as *anaërobic forms.* Reproduction is by simple fission and under favorable circumstances is very rapid. Although extremely small, they are among the most important forms of life. They, together with fungi, cause the souring of milk, the ripening of butter and cheese, and the decay of fruits, vegetables and meats. There are many species which cause diseases, of which some of the most common are tuberculosis, anthrax, pneumonia, diphtheria, typhoid fever and lockjaw. There are other species

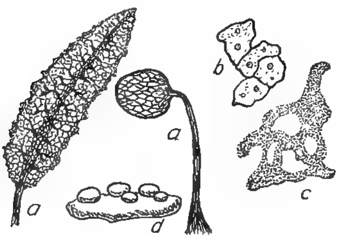

FIG. 124.—(*a*) Types of mature Myxomycetes; (*b*) and (*c*) stages in the development of the plasmodium.

which cause diseases of plants, of which the most common are pear blight, black-rot of cabbage, wilt of cucumber, wilt of tobacco and related plants, crown gall of fruit trees and many other plants. However, it should be remembered that some of them are very useful; among the most important of the useful species is *Pseudomonas radicicola,* which lives in tubercles on the roots of leguminous plants and fixes atmospheric nitrogen in such a form that it can be used by growing plants (see page 204). The study of these forms is of such great importance that it is now generally recognized as an independent subject known as *bacteriology* (page 250). It will be readily seen that it is very closely associated with the study of medicine, plant pathology, soil fertility and with some of the industries.

The *Phycomycetes* are most nearly like the algæ in both structure and reproduction. Some of them produce free swimming zoöspores, but this feature is not nearly so common as in the algæ. They may be divided into the *Oömycetes* and the *Zygomycetes.*

The *Oömycetes* are heterogamous, usually aquatic species, and produce zoöspores. Some of the most common and important genera are *Saprolegnia, Albügo* and *Plasmopara.*

The *Saprolegniales* (Fig. 125) are the water molds. They live on dead insects and other small animals and also on live fish and frogs. They are sometimes very destructive in the fish hatcheries. The filaments project from the body of the host and appear very much like a mass of cotton. The apical cells develop into sporangia which produce great numbers of biciliate zoöspores. The oögonia are terminal and spherical and bear from one to several oöspheres. The antheridia are tubular and may rise from the same or another filament; they come in contact with the oögonia and send out small tubes, which penetrate the oögonial wall. The contents of the antheridium are discharged into the oögonium and fertilization results in the formation of thick-walled oöspores which germinate by the formation of new hyphæ.

Albugo occurs on many plants; among the most common is *A. candida* (Fig. 126), which attacks members of the *Cruciferæ.* The mycelium lives intercellularly in the host, drawing its nourishment by means of haustoria which penetrate the host cells. Whitish blisters appear under the epidermis of the host, which eventually breaks, liberating great numbers of conidia. These spores are borne in chains, are multinucleate and give rise

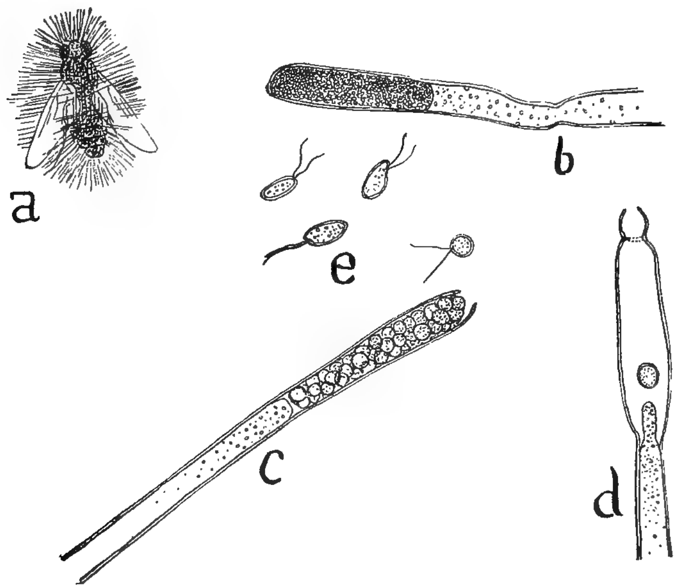

FIG. 125.—Saprolegnia. (*a*) Infested fly; (*b*) immature sporangium; (*c*) mature sporangium; (*d*) same after the escape of the spores; (*e*) free-swimming spores.

to biciliate zoöspores. These zoöspores swim for a time, come to rest and produce tubes which penetrate and infect seedling plants. The sexual organs are formed on the deep-seated mycelia and on separate hyphæ. The oögonium is more or less spherical and multinucleate. The antheridium is multinucleate and produces a small tube which penetrates the oögonium and discharges its contents. The result of this fertilization process is the formation of an oöspore which is liberated by the decay of the host tissues. The oöspore may produce zoöspores or develop a mycelium.

Plasmopara viticola is the cause of the downy mildew of the grape and may be considered as a type of the order *Peronosporales*. The mycelium grows within the leaf and fruit, draws its food supply from them and finally forms a downy white growth on the under surface of the leaf. This growth is made up of *conidiophores* or fruiting filaments. They bear *conidia,* which produce free-swimming biciliate zoöspores. These zoöspores

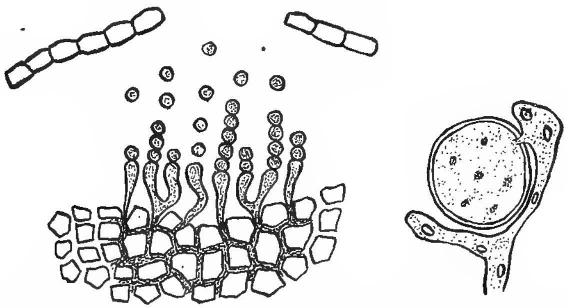

FIG. 126.—Albugo candida showing the formation of the conidia spores just below the epidermis of the host plant and also the antheridium and archegonium.

swim for a few minutes in the moisture on the surface of the leaf, come to rest, lose their cilia and produce new hyphæ which penetrate the leaf through the stomata. The oögonia and antheridia are very similar to those of the *Albugo*. The late blight of the potato is in reality a mildew and is caused by a fungus (*Phytophthora infestans*). It is very similar to the grape mildew and is one of the most important plant diseases.

The *Zygomycetes* are isogamous, aerial, and reproduce by non-motile asexual spores and usually by conjugation. They are well illustrated by the common bread mold, *Rhizopus nigricans,* although they include several other genera.

Rhizopus nigricans is the bread mold fungus (Fig. 127).

It appears as a prominent, white growth on the surface of moist bread, fruits and vegetables. It causes the rotting of stored fruits and vegetables. The mycelium is a branching, cœnocytic filament which penetrates the food material and produces upright, aerial growths bearing sporangia. These sporangia bear great numbers of spores which escape, become dry and sometimes

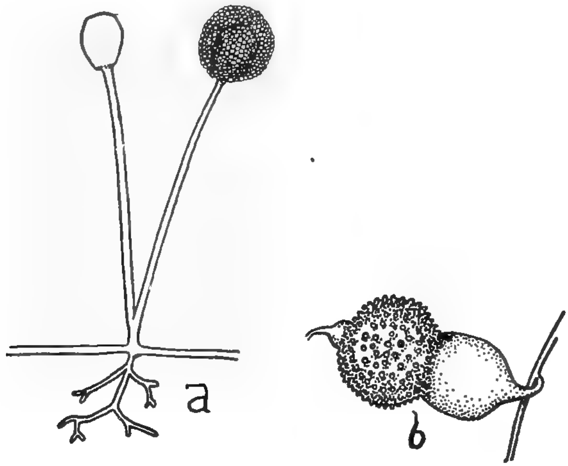

FIG. 127.—Rhizopus nigricans or bread mould; (*a*) entire plant showing sporangia; (*b*) mature zygospore.

live for many years. They also reproduce sexually by the formation of processes which unite to form zygospores.

The *Ascomycetes* contains the largest number of species of any of the divisions of fungi and a great many of them are parasitic. It includes a great many species that are very destructive to agricultural crops; some molds that are used in making cheese, which are of importance in the industries; and some few that are used for food. Many of the saprophytic species are of greater importance than we realize as factors in the decay of organic materials. They have two forms of reproduction—the non-sexual and the sexual. In the sexual method the spores are borne in sac-like structures, known as *asci* (singular *ascus*) and are usually eight in number. The asci are borne in a body known as the *ascocarp*. They do not produce zoöspores. The sexual reproduction is very similar to that of the red algæ from which they have probably descended. For this reason, they are of very great importance in the study of the evolution of the plant kingdom. The fact that so many of the species belonging to this group are very destructive to our agricultural crops makes it one of the most important groups of plants, but we cannot give much attention to it at this time. The following genera may be taken as good examples of the Ascomycetes: *Saccharomyces, Taphrina, Aspergillus, Penicillium, Microsphæra, Peziza, Sclerotinia* and *Morchella.*

The genus *Saccharomyces* (or yeast) (Fig. 128) is one of the very simplest and most important of the Ascomycetes. Each plant is a single, very small, spherical cell which reproduces by the formation of small buds. These buds become separate from the parent plant. Very rarely, under conditions of starvation, the cell becomes transformed into an ascus bearing four spores.

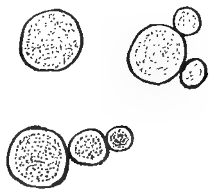

FIG. 128.—Yeast.

These plants cause fermentation or decomposition of sugar, resulting in the formation of alcohol and carbon dioxide. They are used extensively in the making of bread, and in brewing, distilling alcoholic liquors. They feed on the sugar contained in the flour, the carbon dioxide gas is caught in the sticky protein of the dough, expands and causes the phenomenon of "rising."

The genus *Taphrina* contains a number of species that cause diseases on plants, more especially the stone fruits. One of the most important is *T. deformans,* which causes the leaf curl of the peach. The fungus grows within the tissues of the leaf, producing asci on the lower surface. There is no ascocarp and, therefore, the asci are said to be naked.

The genus *Aspergillus* contains a number of species of the green molds which are found on leather, fruits, vegetables, cheese and other organic materials. They produce an abundance of mycelium and numerous conidia, which are arranged in chains which radiate from a common origin. The sexual reproduction is by means of antheridia and oögonia. Fertilization is followed by the formation of an ascocarp bearing eight-spored asci.

The genus *Penicillium* (Fig. 129) contains numerous species of blue molds which are found growing on fruits, vegetables, cheese, bread, leather and other organic materials. Some of them are very important as the causes of decay in fruits, especially oranges and lemons, while others are used for the development

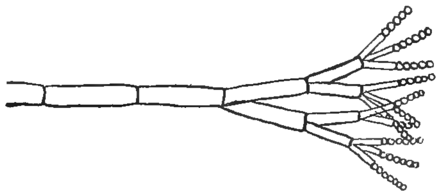

Fig. 129.—Penicillium.

of desirable flavors in cheese. Their reproduction is very similar to that of the Aspergillus.

The genus *Microsphæra* (Fig. 130) is a good type of the powdery mildews which are parasitic on many of the higher plants. They live on the surface of the leaves and are held in place by small haustoria which penetrate the epidermal cells. These surface mycelia give rise to erect sporophores bearing single terminal chains of conidia. The oögonia and antheridia are uninucleate terminal cells. Fertilization occurs in the usual manner and a solitary ascocarp is formed. The ascocarps of the various genera of the powdery mildews present well-defined characters. One of the most common is *M. alni,* which causes the well-known whitish growth on the leaves of the lilac and many other plants in the late summer and fall. Some of the powdery mildews are very destructive to our agricultural crops.

The *Pezizas* (Fig. 131) are cup-shaped and frequently very highly colored. They arise from saprophytic mycelium and are lined with the upright tubular asci and their paraphyses. Many of them are highly colored and very interesting but of little or no economic importance.

The genus *Sclerotinia* contains a number of parasitic species that are very destructive to agricultural crops. One of the most important is *S. cinerea,* which cause the brown rot of the peach. The mycelium grows within the fruit and produces the great mass of chain-like spores on the surface. Under some conditions,

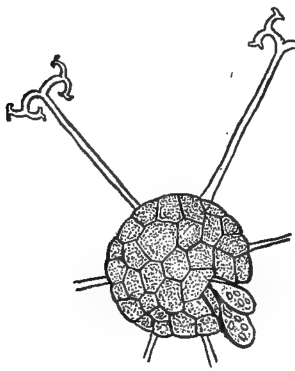

FIG. 130.—Fruiting body of mildew.

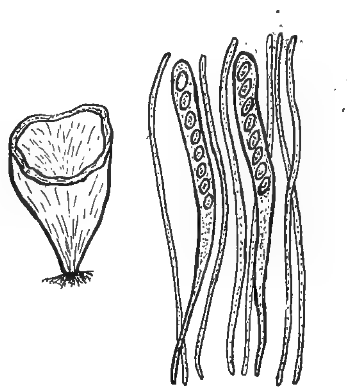

FIG. 131.—Peziza.

the mycelium of the fungus within the old fruits on the ground produces a cup-like growth containing great numbers of asci.

The genus *Morchella* contains some of the large edible fungi. One of the most common species is *M. esculenta,* which is known as the common spring morel and is considered a great delicacy. The large convoluted top is the ascocarp, which, of course, bears the paraphyses and the asci containing eight spores each.

The *Lichens* constitute a peculiar group of plants which are usually included in the Ascomycetes. They grow on rocks, soil, tree trunks, old fences and in festoons from the branches of trees. Each lichen consists of a mass of algæ (usually unicellular) which has been parasitized by a fungus. These fungi (with two exceptions) belong to the Ascomycetes. These two exceptions belong to the Basidiomycetes. In most cases the algæ do not appear to be greatly injured by the fungi, but in some cases the parasitism is very pronounced. The algæ involved in this growth are mostly Cyanophyceæ and Protococcales. Some of the lichens are injurious to the higher plants on which they grow. The so-

FIG. 132.—Smut.

called reindeer moss is a lichen which makes a luxuriant growth and is the most important food of the reindeer.

The *fungi imperfecti* include a very large number of fungi which are known only by their conidiospores. It is very probable that many of these species have no method of reproduction other than by conidia, but many other species have ascospores, and, therefore, belong to the Ascomycetes. Some of them belong to the Basidiomycetes. As soon as the life history of any species is known it is given its proper classification. Many of these species are destructive parasites and are of the very greatest importance in agriculture.

The *Basidiomycetes* include the smuts and rusts which are microfungi and also the large fleshy fungi of which the mushrooms and puffballs are types.

They are divided into the *Proto-basidiomycetes* with a four-celled basidium, each bearing a one-celled spore, and the *Auto-basidiocycetes* with a one-celled basidium bearing four spores.

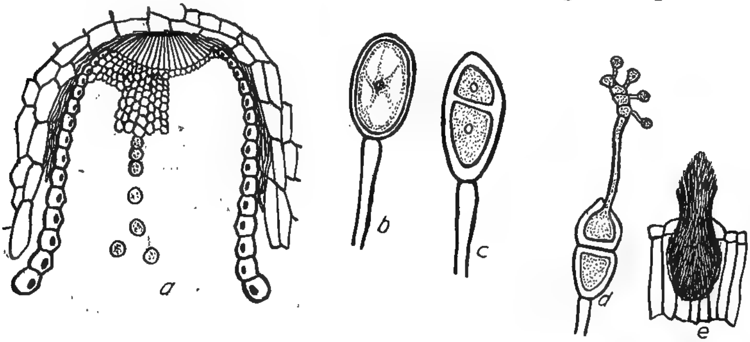

FIG. 133.—Wheat rust; (*a*) cross-section showing the æcial stage on the barberry; (*b*) urediniospore; (*c*) teliospore; (*d*) germinating teliospore showing sporidia; (*e*) pycnidia.

The *Proto-basidiomycetes* is divided into the *Usitilaginales* or smuts and the *Uredinales* or rusts.

The *smuts* (Fig. 132) attack many plants, but may be characterized by the corn smut, *Ustilago maydis.* The mycelium works within the host and finally causes swollen, tumor-like growths, which may appear on any part of the plant. When mature, these masses are filled with spores which germinate the following spring, producing short filaments. Each filament produces spores which are capable of infecting young plants. The smuts are very destructive to many of our cultivated plants. The grain smuts are among the most important causes of plant diseases and destroy many millions of dollars' worth of grain every year.

The *rusts* (Fig. 133) may be illustrated by the wheat rust, *Puccinia graminis.* The mycelium lives within the host, coming to the surface for the production of two kinds of spores. The urediniospores (or uredospores) or summer spores are borne singly and are unicellular. They germinate readily and cause new infections. The teliospores (or teleutospores) or winter spores are borne singly and are two-celled. They germinate the

FIG. 134.—Apple rust

following spring, producing a *promycelium* which bears sporidia in groups of four. The sporidia correspond to the spores in the Autobasidiomycetes. These sporidia germinate and are capable of infecting the barberry and giving rise to the æcidium or cluster cup stage. The æcidiospores are borne in rows in a cup-like growth on the under surface of the leaf. These spores can germinate and infect the wheat. On the upper surface of the barberry leaf we find small flask-shaped organs known as pycnidia (or *spermogonia*) and bearing very small pycnospores.

Their function is uncertain. Although the barberry is an important factor, it is not necessary for the continuation of this fungus on the wheat, the uredospores from one plant can infect another plant and the fungus can be perpetuated indefinitely in this manner. Many of the rusts have only one host; some of them have only two stages and others only one. They are said

FIG. 135. —Cedar rust.

to be the most highly specialized parasites in the plant kingdom. Other very important species are the apple rust (*Gymnosporangium juniperi-virginiana*), which has its æcial stage on the apple (Fig. 134) and its telial stage on the red cedar (Fig. 135); and the blister rust of the white pine (*Cronartium ribicola*), which has its æcial stage on the white pine and the other two stages on the currants and gooseberry. The rusts take an annual toll of many millions of dollars from the wealth of the country.

The *Autobasidiomycetes* are the true *Basidiomycetes* and are known as the fleshy fungi. Some of the most important families are the *Agaricaceæ,* the *Hydnaceaæ,* the *Polyporaceæ* and the *Lycoperdaceæ.* The first of these families may be illustrated by almost any common mushroom of the genus *Agaricus.*

The *Agaricaceæ* (Fig. 136) or common mushrooms and toadstools are well known. The most common type has a stipe or

Fig. 136.—Two specimens of mushrooms. The one on the left shows the annulus or ring.

stem and a pileus or cap bearing the lamellæ or gills. They arise from a *button* which is produced from a mycelial growth that may have been in existence for a long time. The button persists in many species as a *volva* or cup. When in the button stage the edge of the pileus it attached to the stipe by a membrane known as the *velum.* If it clings to the stipe it is known as the *annulus* or ring. The *basidia* are borne on the surface of the gills and usually bear four spores each.

There are a great many other types of *Agaricaceæ.* Some of them produce shelf-like sporophores with the gills on the under side. They form very conspicuous growths on trees and fallen timber.

The *Hydnaceæ* have tooth-like growths on which the spores are borne; the *Polyporaceæ* have pore-like structures on which the spores are borne, and the *Thelephoraceæ* have a smooth surface on which the spores are borne.

The *Lycoperdaceæ* or puffballs have more or less globular sporophores made up of two well-defined layers or peridiums enclosing great masses of spores. They are very prominent and well-known forms.

Some of the fleshy fungi are valuable for food, while others are very poisonous. Some of them are very destructive to growing trees and to lumber. The fact that many of the fungi are destructive to other plants, especially to our agricultural crops, makes them one of the most fruitful fields of study. The study of the fungi is known as *mycology* and may be considered the basis of *plant pathology* (see page 250).

LABORATORY EXERCISES.

Exercise 1. Examine such material of Myxomycetes as may be available.

Exercise 2. Examine type specimens of bacteria.

Exercise 3. Rhizopus nigricans. (This fungus can be readily grown on moist bread under a bell jar.) Note the growth on the bread, especially the upright sporangiophores bearing the sporangia.

Examine under the microscope and note the delicate hyphæ and its method of branching. Note the rhizoids at the base. Note the sporangium and its columella and spores. Examine fruiting material for zygospores. Compare with the algæ which you have studied.

Germinate some of the spores in a hanging drop. See exercise for germinating pollen grains, p. 107. Water can be used instead of sugar solution.

Exercise 4. Saprolegnia sp. (This fungus can be readily grown on dead flies, floated on pond water.) Note the growth of mycelium from the body of the fly. Examine the mycelium under the microscope and note the granular protoplasm, the terminal sporangium and if possible the zoöspores emerging from a mature sporangium.

Exercise 5. Albugo candida. Examine prepared slides and note the arrangement of the conidia and the formation of the oöspores.

Exercise 6. Plasmopara viticola B. & C., the downy mildew of the grape. (This material can be kept dry or preserved in alcohol or formalin.) Examine a grape leaf and note the location of the fungus and its effect on the host. Examine some of the fungus under the microscope and note the conidiophores and conidia spores.

Exercise 7. Saccharomyces cerevisiæ Meyen., or bread yeast. (Put a small piece of an ordinary yeast cake into a glass of water containing a very small amount of sugar. Keep in a warm place for a few hours.) Examine a drop of this mixture under the microscope. Note the size and shape of the cells, the vacuoles and the budding.

Exercise 8. Microsphæra alni or any other powdery mildew. Note the relation of the fungus to the host. Examine the mycelium and the black fruiting bodies under the microscope. Note the appendages. Crush the fruiting bodies by pressing on the cover glass with the rubber of a lead pencil. Note the protruding asci and spores.

Exercise 9. Nectria ipomœa Halsted. (This fungus will be found on sweet potatoes in advanced stages of decay.) Examine the fruiting body. Then crush and examine under the microscope. Note the asci and spores.

Exercise 10. Penicillium sp. (This material can be very readily obtained from decaying oranges or other fruits and from many other sources.) Examine under the microscope and note conidiophores and conidia spores. Germinate some of the spores in hanging drop. See Exercise 3.

Exercise 11. Peziza sp. Examine the entire plant. Examine prepared slides and note asci and paraphyses.

Exercise 12. Lichen. Examine the entire plant. Examine freshly cut sections and note the relationship of fungus and algæ. Examine a section through the fruiting body and note the asci.

Exercise 13. Ustilago maydis Bech., or corn smut. Examine the fungus and note its position and relation to the host. Examine some of the spores under the microscope.

Germinate some of the spores in hanging drops prepared of diluted boiled stable manure water. (Spores will germinate more readily if they have been frozen.)

Exercise 14. Other smuts may be studied in the same manner if circumstances permit.

Exercise 15. Puccinia graminis Pers., or wheat rust.

I. Examine a diseased barberry leaf and note the position of the fungus. Examine prepared slides and note the cup-like bodies and the æcidiospores. Also note the pycnia.

II. Examine wheat plant and note the reddish spots on the stems and leaves. Scrape some of these spots and examine under the microscope and note the one-celled urediniospores.

III. Examine the wheat plant and note the black patches on the leaves. Scrape off a little of this material, examine under the microscope and note the teliospores.

Exercise 16. Gymnosporangium juniperi-virginiana or rust of cedar and apple.

I. Examine the leaf or fruit of the apple and note the appearance of the growth. Examine prepared sections and note the æciospores.

II. Examine the fungus growths from the cedar. Examine the teliospores.

Exercise 17. Agaricus sp. Examine a mature fungus and note cap, stipe and annulus. Examine prepared slides and note the arrangement of the spores.

CHAPTER XXVI

BRYOPHYTES

THIS group of plants consists of the liverworts (*Hepaticæ*) and mosses (*Musci*). They are of very little economic importance, but it is very necessary to have a thorough knowledge of them in order to understand the evolution of the higher plants. The evolutionary evidence indicates that they were derived from the algæ and that they were the first land plants in the history of the plant kingdom. A high moisture content is necessary for the growth of most of the mosses; in fact, some species live in the water. Their life history involves what is known as the *Alternation of Generations; i.e.*, a life history consisting of two types of plants alternately producing each other; one generation known as the *gametophyte* producing sexual organs bearing the gametes or sex cells, and one generation known as the *sporophyte* producing non-sexual spores.

The *archegonium* or female sex organ is characteristic of both the *Bryophytes* and the *Pteridophytes*. In fact, these two great groups are sometimes referred to as the archegoniates. The appearance of the highly developed, multicellular *antheridium* or male sex organ is also very characteristic of the *Bryophytes*.

The *Hepaticæ* is a very old group of plants which were probably of much greater importance in some earlier period of the history of the plant kingdom than at present. It is divided into three divisions: (1) *Marchantiales*, (2) *Jungermanniales* and (3) *Anthocerotales*. One of the most common and most conspicuous species in *Marchantia polymorpha* (Figs. 137, 138, 139, 140, 141), which is a most excellent type of study.

The *gametophyte* of *Marchantia polymorpha* is a highly developed thallus (Fig. 137), much larger than in most of the *Hepaticæ*. It is flat, branching and several layers of cells in thickness. It is much thicker in the axial line than on the margins and the upper surface is marked into rather definite areas which give it a superficial resemblance to an animal liver (Fig. 138) and therefore the common name "liverwort." In the center of each area is a small opening into a chamber which corresponds to the area. The epidermal cells are transparent, but arising from the floor of this chamber are many delicate chlorophyll-bearing cells. However, chlorophyll is not restricted to these cells, but is also found in other cells. On the lower axial region are numerous hair-like structures known as *rhizoids* and corresponding to the root hairs of the higher plants. They absorb water and other raw food materials. The air has free access to the cells within the chambers and affords the necessary supply of carbon dioxide. The sunlight passes through the upper epidermal cells (Fig. 139). Therefore, it will be seen that the plant has all the factors necessary for photosynthesis. The anterior end of the plant is notched, and it is from this point that the growth occurs.

Fig. 137.

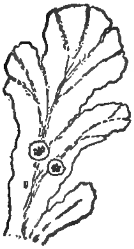

Fig. 138.

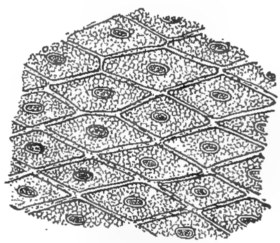

Fig. 137.—Marchantia polymorpha showing two cupules bearing gemmule.
Fig. 138.—Surface view of Marchantia polymorpha very much magnified.

The non-sexual reproduction is by means of small buds or *gemmæ* which are borne in tiny cups or *cupules,* along the axial line of the upper surface. They are capable of growing into new gametophytes (Fig. 137).

The sexual organs (Fig. 140) are borne in receptacles or special branches arising from the upper surface of the thallus or gametophyte body. The archegonial and antheridial branches are borne on different gametophytes and therefore the plant is diœcious. The *archegonial* branch (Fig. 140, *a*) bears a star-shaped body which gives rise to the *archegonia.*

The *archegonium* is flask-shaped and the egg cell is borne in the body of the structure. The neck consists of a single row of eight cells surrounded by a single layer of cells; when the egg cell is mature, the axial row of cells becomes liquefied. The *antheridial* branch (Fig. 140, *b*) bears a lobed, disk-shaped body with flask-shaped cavities which open on the upper surface. The antheridia are borne singly in these cavities and produce great numbers of sperms which finally escape and swim in the

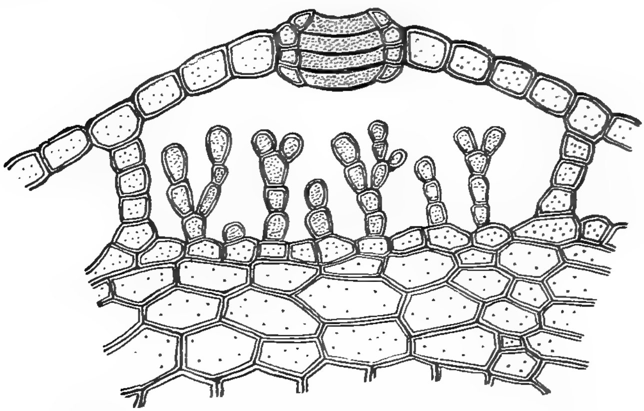

FIG. 139.—Cross-section of M. polymorpha showing structure.

thin film of moisture over the surface of the plants. Some of these sperms reach the archegonia, swim down the neck, and one unites with the egg or oösphere (fertilization).

The cell which is formed by the union of the two sex cells or gametes is the fertilized egg and is the beginning of the next or sporophyte generation. The young sporophyte develops into foot, seta and capsule. The capsule bears spores and fiber-like, spirally thickened cells known as *elaters.* When the spores are mature, the elaters expand, bursting the capsule and scattering the spores.

The basal part of the archegonium persists as a cup-shaped structure and is known as the *calyptra.* The spores germinate and produce new gametophytes. The complete life history is illustrated in Fig. 141.

The genus *Riccia* also belongs to the *Marchantiales* and contains a number of species, some of which are terrestrial and others aquatic. They are smaller than *M. polymorpha* and the antheridia and archegonia remain embedded in cavities of the thallus. They are the simplest of the *Hepaticæ*.

The *Jungermanniales* contains a larger number of species than either of the other two groups. They grow under conditions ranging from the extremely wet to the extremely dry. They are most abundant in the tropics and grow most commonly on the ground, on tree trunks and on leaves. They are divided into two groups, the *thallose* forms, which resemble the *Marchantiales,* and the *foliose* forms, which resemble the mosses, but there is a gradual gradation between the two groups. However, the distinctive characters of the *Jungermanniales* is to be found in the archegonia and the sporophyte.

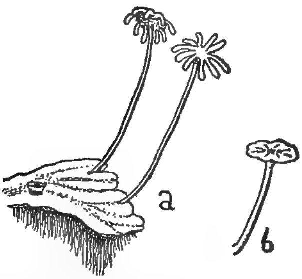

Fig. 140.—(*a*) female plant of Marchantia polymorpha bearing two archegonial branches; (*b*) also a single antheridial branch from a male plant.

The *Anthocerotales* is a small, temperate zone group, which is thought by many workers to represent the ancestral forms of the *Pteridophytes.* We cannot discuss this order in a limited work of this kind.

It will be noted that in the *Hepaticæ* the *gametophyte* is much larger than the sporophyte and that there are no true roots, stems or leaves. There is a differentiation of the cell structure but no collenchyma, sclerenchyma, fibrous, tracheary, sieve or laticiferous tissues.

The *Musci* or mosses are also a very old group of plants which are more highly differentiated than the *Hepaticæ.* They are widely distributed and were much more abundant during the carboniferous age of the earth's history than at the present time.

They are divided into three groups: (1) *Sphagnales,* (2) *Andreæales* and (3) *Bryales.*

The *Sphagnales* were especially abundant during the carboniferous age and are largely responsible for the great beds of coal. They are sometimes known as the peat or bog mosses and are abundant in some localities, especially the swampy regions

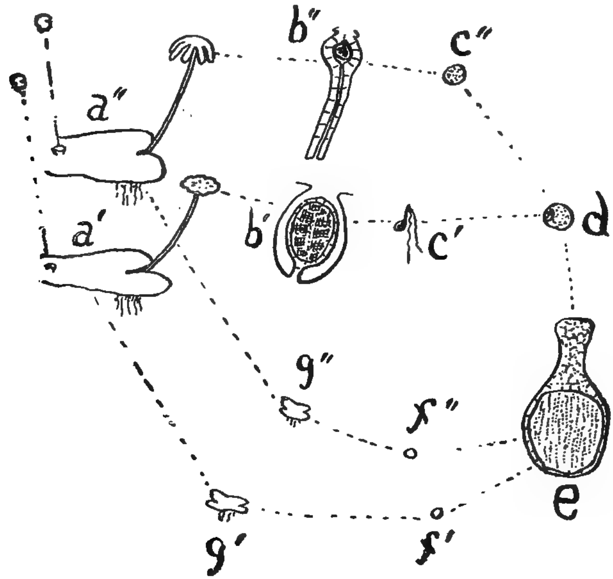

FIG. 141.—Diagrammatic representation of the life cycle of Marchantia polymorpha; (*a*) mature male plant; (*a''*) mature female plant; (*b'*) antheridium; (*b''*) archegonium; (*c'*) sperm; (*c''*) ovum; (*d*) oöspore; (*e*) young sporophyte; (*f'*) and (*f''*) spores; (*g'*) and (*g''*) young plants.

of the higher altitudes. They are the characteristic types found in cranberry bogs of the eastern and northern parts of the United States. They were used extensively during the recent war for dressing wounds.

The *Andreæales* is a small order which we will not study.

The order *Bryales* (Fig. 142) includes the most common and widely distributed types of the present time. The gametophyte body is a branching filament (*protonema*) which may be considered a thallus. It produces the erect, leafy shoots (*gametophores*) with which we are familiar as moss plants.

The stem of this gametophore consists of elongated paren-

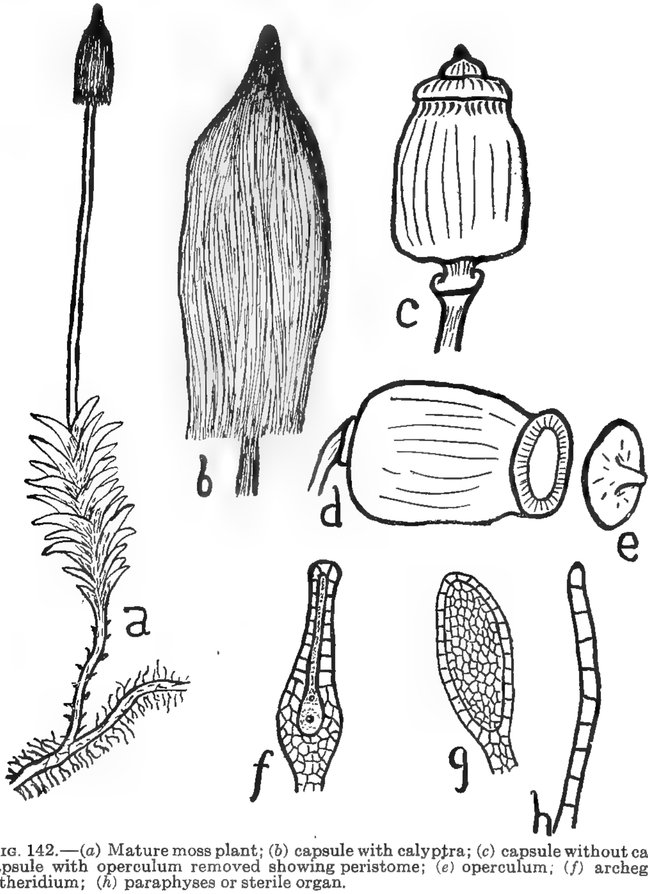

FIG. 142.—(*a*) Mature moss plant; (*b*) capsule with calyptra; (*c*) capsule without calyptra; (*d*) capsule with operculum removed showing peristome; (*e*) operculum; (*f*) archegonium; (*g*) antheridium; (*h*) paraphyses or sterile organ.

chyma cells, but there is no further differentiation into tissues such as are found in the higher plants. The leaves are not true leaves such as are found in the higher plants, but each leaf consists of a single layer of cells with a rudimentary midrib of elongated thick-walled cells. Both the gametophyte and gametophore obtain their nourishment by means of rhizoids which penetrate the soil.

The plants are diœcious and the archegonia and antheridia are borne in the tops of the gametophore shoots. They are slightly different in form but practically the same as the corresponding structures in the *Hepaticæ.* Associated with them are clusters of multicellular, hair-like bodies known as *paraphyses.*

Fertilization occurs in the same manner as in the *Hepaticæ,* and the young sporophyte develops into foot, seta and capsule. The *calyptra* is ruptured near the base and carried upward, resting on the *capsule* as a hood. When the calyptra is removed, we find the *operculum* or lid-like structure, which can also be removed, exposing the *peristome.* The spores are borne in a cylindrical zone within the capsule. The peristome consists of rows of teeth attached at the rim and pointing inwards. It functions in the distribution of the spores.

The fully developed moss plant possesses stem-like and leaf-like structures, but a careful study will show that they are very simple as compared with the corresponding organs of the higher plants. The so-called stem is very simple, consisting of elongated parenchyma cells instead of the highly differentiated tissues borne in the stems of the higher plants. The leaf-like organs usually consist of only one layer of undifferentiated cells, except for a rudimentary midrib consisting of small, elongated cells.

LABORATORY EXERCISES.

Exercise 1. Marchantia polymorpha L.

I. *Gametophyte.* Examine the thallus. Note its dorsiventral position on the ground, the notch at the tip, its greatest thickness along the axial line, the areas on the dorsal surface and the rhizoids on the ventral surface.

Examine some of the rhizoids from the ventral surface under the microscope. Note the walls and scattered peg-like projections into the cavity.

Examine a cross section of the thallus. Note the variation in the cells from the dorsal to the ventral surfaces, especially the epidermal cells, the cells around the stomata and the special chlorophyll-bearing cells within the cavities.

Examine a thallus showing the cupules containing the gemmæ.

Examine the reproductive branches. Note their location and differences.

Examine prepared sections showing the antheridia. Note their location and cell structure.

Examine prepared section showing archegonia. Note their location and cell structure.

II. *Sporophyte.* Examine a plant in which the sporophytes are almost mature. Note their location and general character.

Crush a capsule and examine the spores and elaters.

Exercise 2. Moss plants.

1. *Gametophyte.* Examine an ordinary moss plant. Note the primitive stem, the arrangement of the leaves, and the rhizoids.

Examine a rhizoid under the microscope and compare with those of *M. polymorpha.*

Examine a single leaf. Note the thickness, the variation in cells and the absence of stomata.

Examine a protonema under the microscope. Note the oblique septa. Compare with the algæ.

Examine a preparation from the tip of a male plant and note the antheridia and paraphyses.

Examine a preparation from the tip of a female plant and note the archegonia and paraphyses.

Sporophyte. Examine a mature plant and note the setæ, capsule and calyptra. Remove the calyptra and operculum and note the peristome.

Examine some of the spores under the microscope.

CHAPTER XXVII

PTERIDOPHYTES

THIS group is much more highly differentiated than the preceding in that we now find true roots, stems and leaves composed of tissues very similar to those found in the higher plants, although the arrangement differs in some degree. They are very similar to the Bryophytes in that they possess alternation of generations, but in this group the Sporophyte is larger than the Gametophyte and becomes entirely independent of it.

The archegonium is also a characteristic organ and very similar to that found in the Bryophytes. We have already called attention to the fact that the Bryophytes and Pteridophytes are sometimes referred to as the archegoniates. Owing to the fact that the Pteridophytes contain fibro-vascular tissues, they are sometimes referred to as the vascular cryptogams.* This group was no doubt much larger in past ages than at the present time and may have been an important factor in the formation of the great beds of coal. Some of the ancient species were very large, in fact, tree-like in size and appearance. The group includes: (1) *Lycopodales* or club mosses, (2) the *Equisetales* or horsetails or scouring brushes, (3) *Filicales* or true ferns (Fig. 143) and some smaller divisions. We will omit the first group.

The *Gametophyte* generation of a true fern (Fig. 144) is a small thallus structure resembling a liverwort and known as the *prothallus*. It lies flat on the ground and has numerous rhizoids. In some species the prothallia are monœcious and in others diœcious. The *archegonia* are borne on the under surface of the prothallium, the body or center embedded in the thallus and the

* *Cryptogam* is an old term meaning "hidden marriage," and is used to include all plants other than the Spermatophytes.

neck usually slightly curved. The *antheridia* are also borne on the under surface and are usually more or less spherical. The fertilization occurs in the same manner as in the Bryophytes, and the resulting fertilized cell is the young *Sporophyte,* which has a history quite different from that of the Bryophytes.

The young *Sporophyte* gives rise to four groups of cells known as the foot, rudimentary leaf, stem and root. The foot is

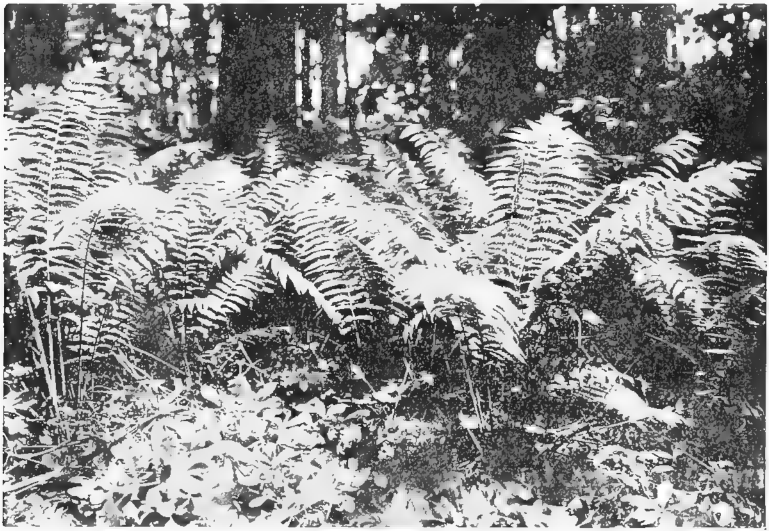

Fig. 143.—A fern glade.

a temporary organ through which the young Sporophyte receives its nourishment. When the young Sporophyte becomes established the foot is of no further use and the prothallium or Gametophyte generation disintegrates. The first root enters the soil, the first leaf grows upward and the stem assumes its characteristic form, structure and function. Therefore, we have a Sporophyte generation with true root, stem and leaf organs which is independent of the small Gametophyte through which it came into existence. We will not attempt to study the root and stem, but they are made up of tissues which are the same or similar to those of the Spermatophytes.

The leaves (or fronds) (Figs. 144, 145, 146, 147, 148, 149) have a structure very similar to that of the Spermatophytes. On the backs of the fronds will be found characteristic brown

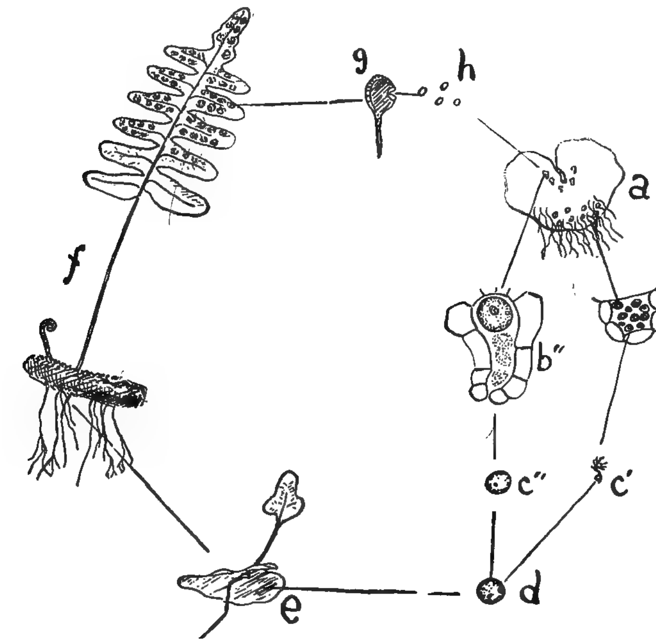

FIG. 144.—Diagrammatic representation of the life history of the fern: (*a*) prothallium; (*b'*) antheridium; (*b''*) archegonium; (*c'*) sperm; (*c''*) ovum; (*d*) oöspore; (*e*) prothallus and young fern; (*f*) mature fern showing underground stem, root and leaf-bearing sori; (*g*) sporangium; (*h*) spores.

spots which vary in size and shape dependent on the species. They are known as *sori* (singular, *sorus*) and in most species are covered with very thin membranes known as *indusia* (singular, *indusium*). These sori are composed of *sporangia,* which in the typical ferns are stalked bodies. They can be readily represented by two watch glasses placed with their concave sides together. The spores are borne within this structure. The marginal cells for about two-thirds of the circumferences are small and thick-walled, while the others are large and thin-walled. When mature the absorption of water by and evaporation from this ring of cells is uneven, resulting in a rupturing of the sporangium and a scattering of the spores. These spores germinate and produce new prothallia or Gametophytes.

The Differentiation of the Sporophylls, Sporangia and Spores.—It will be readily seen that the leaves (or fronds) of the ferns serve two very distinct functions, photosynthesis and

FIG .145.

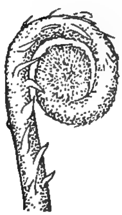

FIG. 146.

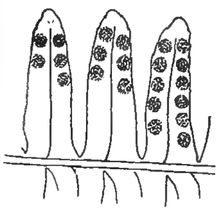

FIG. 147.

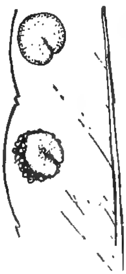

FIG. 148.

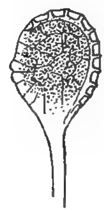

FIG. 149.

FIG. 145.—Young fern leaf showing method of unrolling.
FIG. 146.—Part of fern leaf showing sori or fruit clusters.
FIG. 147.—Part of fern leaf showing sori with indusium.
FIG. 148.—Sporangium from fern sorus.
FIG. 149.—Fern spores from sporangium.

bearing sporangia which contain non-sexual spores. The photosynthetic function is the same in all chlorophyll-bearing plants. The leaves of some ferns perform both functions. A fern leaf which bears sporangia is known as a *sporophyll.* The leaves of some ferns are so differentiated that certain parts serve for bearing sporangia only. In other species certain leaves serve one function and others serve the other function. Furthermore, in some species of the Pteridophytes certain sporophylls bear *microsporangia* and others *macrosporangia;* the former being known as *microsporophylls* and the latter as *macrosporophylls.* The microsporangia bear *microspores* which produce male

Gametophytes and macrosporangia bear *macrospores* which produce female *Gametophytes.*

The *Equisetales* (Fig. 150) or horsetails or scouring rushes is a small group of fern-like plants which grow from underground stems or rhizomes. One of the most common species is *Equisetum arvense.* These underground stems bear tuber-like storage organs and the aerial stems are produced annually. There are two types of aerial stems; one is branched, giving a

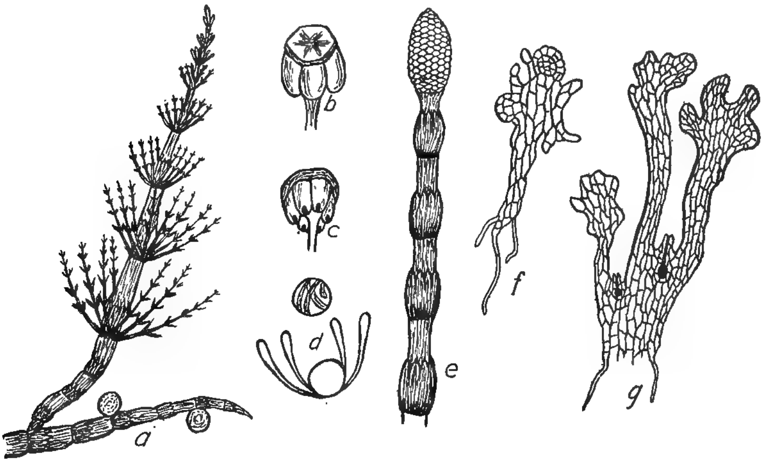

FIG. 150.—Equisetum arvense. (*a*) Underground stem and leafy shoot; (*e*) sporophyll; (*b* and *c*) sporangia; (*d*) spores showing elaters; (*f*) male prothallus; (*g*) female prothallus.

bushy effect, grows throughout the summer, is green and serves for foliage. The other bears rudimentary, collar-like structures (or fused leaves) at the nodes and a cone-like structure (or strobilus) at the top. These cones are made up of specialized leaves (sporophylls) bearing the spores. Each spore has four elaters, all attached at one point, which respond to moisture, winding and unwinding in a manner which helps in their distribution. The Gametophytes are of two kinds (diœcious), male and female, and the archegonia and antheridia are practically the same as those found in the ferns.

The *Lycopodiales* or club mosses have the general appearance of large mosses and are sometimes called ground pines. The life history is very similar to that of the ferns.

Uses of Pteridophytes.—This great group of plants is of very little economic value except for ornamental purposes. However, the collecting and growing of ferns involves very large investments of capital.

LABORATORY EXERCISES.

Exercise 1. Use any typical fern that may be convenient.

Sporophyte. Examine surface and cross-sections of the leaf and compare with the leaf of the higher or flowering plants. Note the sori on the lower surface of the leaf. Note the indusium if present.

Remove a sorus and examine under the microscope. Note the structure of the sporangia. Also note the opening of the sporangia and the scattering of the spores.

Gametophyte. Examine the prothallus and compare with *M. polymorpha.* Note its form, thickness, rhizoids, etc.

Examine a prothallus from which a young Sporophyte is just starting.

Exercise 2. Lycopodium lucidulum Mx., or other species of club moss. Note the appearance and character of the entire plant. Note the location of the sporophylls and the spores. If *Selaginella* or *Isoetes* is available, note the two kinds of spores.

Exercise 3. Equisetum arvense L., or horsetail. (Collections of this material should be made at different times.) Examine the entire plant and note the underground stem, the sterile and the fertile shoots.

CHAPTER XXVIII

SPERMATOPHYTES

THIS is the highest group of plants and is characterized by the production of seeds. The plants belonging to this group possess highly developed organs, such as roots, stems and leaves, composed of the highly differentiated tissues which we have already studied (Chapter II). The Gametophyte plant body is very small and the Sporophyte plant body very large. Furthermore, the Gametophyte body is dependent on the Sporophyte body, which is exactly the reverse of the conditions found in the Bryophytes and Pteridophytes.

The principal divisions of the Spermatophytes are shown on page 304.

The *Gymosperms* are not so highly developed as the *Angiosperms* and possess characters showing their close relationship to the Pteridophytes. They were much more important in past ages than at present time and many of the ancient species are now extinct.

The *Cycadales* are tropical plants and are very closely related to the Pteridophytes. The most familiar species is *Cycas revoluta* (Fig. 151), which is very frequently grown in greenhouses. The sporophyte is a columnar stem, bearing at its apex a number of large fern-like leaves. It bears a close resemblance to the tree ferns. In some of the small species, the stem is small and underground, while in some of the large species it may be as much as fifty feet in height. The cycads bear cones (or strobili) very similar to those on the pines. The staminate strobili are composed of microsporophylls, bearing microsporangia, which contain microspores. The pistillate strobili are composed of macrosporophylls, bearing macrosporangia, containing the macrospores.

- *Spermatophytes*, or seed-bearing plants.
  - *Gymnospermæ*,* or cone-bearing plants.
    - *Cycadales* or cycads, tropical or sub-tropical, which are fern-like in character, although some of the larger species resemble the palms. Very prominent in past ages, but less than 100 species exist at the present time. Most primitive of the seed plants.
    - *Pinales*, or true cone-bearing plants. Mostly evergreens. More prominent in the past than at present, but less ancient than the Cycadales, including about 300 species. See page 306.
  - *Angiospermæ*, or true flowering plants.
    - *Monocotyledons;* the embryo with one cotyledon; stems mostly of parenchyma, with scattered fibro-vascular bundles; leaves smooth, simple, linear or lance shaped, mostly sessile and with rare exceptions parallel veined; flowers mostly simple and in the majority of species the parts are arranged in whorls of threes. About 25,000 species. See page 312.
    - *Dicotyledons;* the embryo with two cotyledons; stems with fibro-vascular bundles arranged in a circle about central axis of pith and a well-defined cambium; leaves with petioles, simple or compound and net-veined; flowers ranging from very simple forms resembling the most primitive of the Monocotyledons to very complex forms, the parts most frequently arranged in whorls of fours or fives. About 100,000 species. See page 331.

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* The Gymnospermæ consist of seven recognized orders: (1) *Cycadofilicales*, (2) *Bennettitales*, (3) *Cycadales*, (4) *Cordaitales*, (5) *Ginkoales*, (6) *Pinales* and (7) *Gnetales*. The first, second and fourth are extinct. We will consider the third and sixth only.

Only one of the macrospores develops into a Gametophyte, which remains enclosed in the sporangium. Several archegonia

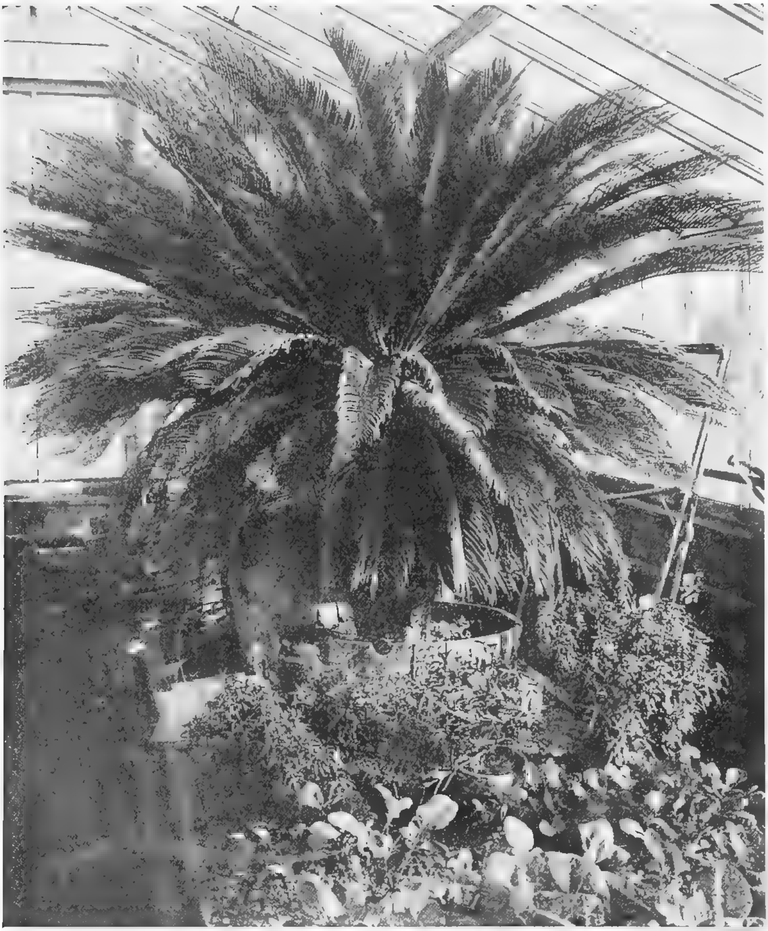


FIG. 151.—Cycas revoluta.

which are somewhat simpler than those of the Pteridophytes are developed at the micropolar end. The microspores (or pollen grains) develop into very small three-celled Gametophytes, are carried by the wind, some of them passing through the micropyle, where they come in contact with the macrosporangium. They develop tubes which grow through the nucellus, finally reaching the archegonia. During this time the generative cell enters the pollen tube and thence into the pollen chamber, divides into two cells, the stalk cell and the body cell. This body cell gives rise

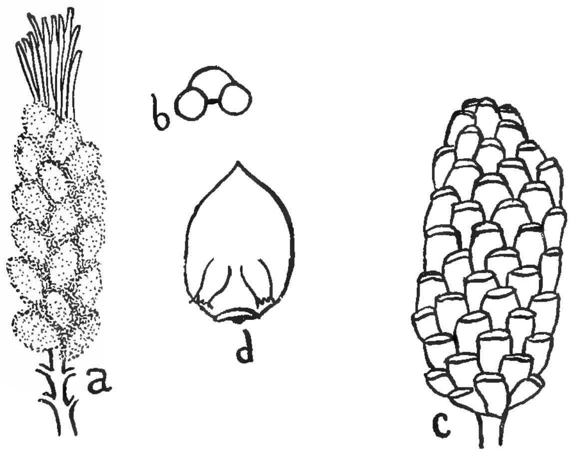


FIG. 152.—(*a*) Cluster of staminate cones; (*b*) pollen grain; (*c*) pistillate cone; (*d*) scale from pistillate cone showing two ovules.

to two ciliate sperm cells which swim in the fluid of the chamber and finally reach the egg cell of the archegonium. In comparison with the ferns, it will be noted that the number of sperms is few and that they never escape from the tube. The result of fertilization is the formation of a seed.

The *Pinales* includes the pine, larch, spruce, fir, cypress, arbor vitæ, cedars and junipers. They are characterized by cone fruits and are frequently referred to as "conifers." However, in some of the species the cones are modified into berry-like fruits, such as are formed in the junipers. There are about 40 genera and 350 species and they are found mostly in the temperate zones. The pine is a good type for study.

As a matter of convenience we will reverse our order of presentation and give the Sporophyte the first consideration. These trees have roots and stems very similar in structure to the Angiosperm plants which we have already studied. However, the leaves are very much modified, ranging from flat blade-like structures to narrow needles. The mesophyll is greatly reduced and the epidermis very pronounced as compared with that of most Angiosperms. There are two types of cones, the *pistillate* or

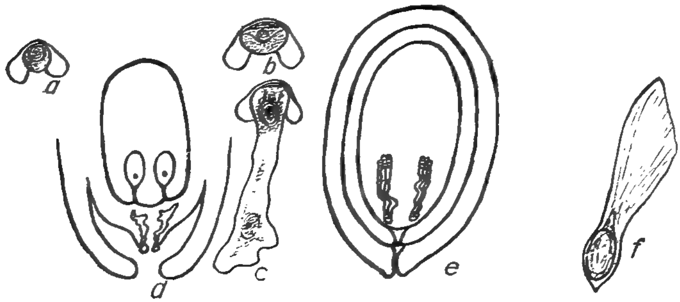


FIG. 153.—(*a*) Pollen grain; (*b*) same showing first division; (*c*) pollen tube; (*d*) sporangium showing integument, micropyle and archegonia; (*e*) same showing embryos; (*f*) mature seed.

ovulate and the *staminate*, which are composed of scales or sporophylls (modified leaves) arranged in spirals.

When the pistillate cones are mature the macrosporophylls spread apart, exposing two ovules or macrosporangia on the upper surface of each. At the lower point of each macrosporangium are two processes or extensions of the integument; the opening between them is the *micropyle*. The inner part of the macrosporangium is called the nucellus and contains one or more macrospores which become the female prothallia or Gametophytes. The archegonia are formed in the nucellus near the micropyle (Figs. 152, 153).

The staminate cones are made up of microsporophylls which spread apart exposing two small *sacs* or anthers (microsporangia) on the under surface of each. They contain great quantities of *pollen* (or microspores) which escapes and is carried by the wind, some of it falling into the open pistillate cones, where it comes directly in contact with the ovules (*i.e.,* pollination). After pollination the macrosporophylls close, forming a compact cone (Figs. 152, 153).

The microspores consist of single cells, each with two expanded wings which facilitate their transportation by the wind. The divisions of the single-celled microspore gives rise to a very small, few-celled *male prothallium* (or Gametophyte) bearing two sperms. These sperms are not motile and never escape as in the preceding groups, but pass down a tube formed by a growth of the male prothallium until they reach the archegonium, when fertilization occurs as in the preceding groups. The fertilized cell is a young Sporophyte (or embryo) and is surrounded by parts of the female Gametophyte, the nucellus and the integuments. In other words, we now have what is known as a " seed " composed of the parts just mentioned. The integuments produce a wing-like structure by which the mature seed can be readily carried by the wind (Fig. 153). When the seeds are mature, the macrosporophylls spread apart and permit them to fall out.

In order to get a connected understanding of the relationship of the various groups of plants we should now review Chapter VI on the flower, giving special attention to the part on reproduction. The carpels of the pistil are the *macrosporophylls* and the *ovule* (or more strictly the nucellus) is the *macrosporangium.* One cell (occasionally two or more) of the macrosporangium becomes more prominent than the surrounding cells and is readily recognized by its size and the rich character of its contents. The future history of this cell varies in different species of plants, but in most cases it eventually gives rise to four cells which are known as the *megaspores.* In most cases only one megaspore survives and that one is usually the one farthest from the micropyle. It enlarges very rapidly, absorbing the other three megaspores and some of the cells of the nucellus. The nucleus divides into two, four and then eight, giving rise to the *embryo sac* (page 96), which is the female Gametophyte. The synergids and egg (page 97) correspond to the archegonium of the preceding groups.

The *stamens* are the *microsporophylls,* the chambers of the anther are the *microsporangia* and the pollen grains are the *microspores.* The division of the microspore results in a very small and simple male Gametophyte and antheridium bearing two sperm cells. Fertilization has been described (page 98).

The Pinales includes but one family, the *Coniferæ,* which contains several genera as follows:

1. *Pinus,* leaves in clusters of 2–5; staminate cones at base of new shoot in spring, pistillate cones single or grouped back of terminal bud or lateral on new shoot. Mature fruiting cone consisting of imbricated, woody carpels or sporophylls, persistent, spreading when ripe and dry. Seeds nut-like, with fragile wing and two for each carpel. The most common species are *P. strobus* (white pine), *P tæda* (loblolly or old field pine), *P. rigida* (pitch pine), *P. pungens* (table mountain pine), *P. virginiana* (Jersey or scrub pine), *P. banksiana* (gray or northern scrub pine), *P. echinata* (yellow pine), *P. resinosa* (red pine) and *P. palustris* (long-leaved or Georgia pine).

2. *Picea,* leaves sessile and keeled on both sides; staminate cones axillary and on shoots of the preceding year; pistillate cones terminal and maturing during first year; carpels thin and persistent. The most common species are *P. mariana* (black spruce) and *P. canadensis* (white spruce).

3. *Tsuga,* leaves flat and petioled; staminate cones in axils of last year's leaves; pistillate cones at end of last season's lateral branchlets; cones maturing during first year and pendulous, carpels thin and persistent. This genus is represented by *T. canadensis* (hemlock).

4. *Abies,* leaves solitary, keeled and persistent; staminate cones in axils of last year's leaves; pistillate cones erect and on upper side of branches; cones maturing during first year, car-

pels thin and deciduous at maturity. This genus is represented by *A. balsamea* (balsam or balm-of-gilead fir).

5. *Larix,* leaves flat, usually in fascicles, and deciduous; staminate cones developed from leafless buds; pistillate cones from leafy buds; cones maturing during first year and pendulous, carpels persistent. The genus is represented by *L. laricina* (American black larch or tamarack).

6. *Taxodium,* leaves flat, mostly fascicled and deciduous; staminate and pistillate cones on same branches; mature cones of very thick-angular carpels. This genus is represented by *T. distichum* (American bald cypress).

7. *Chamæcyparis,* leaves small, scale-like or awl-shaped and closely appressed—imbricated; staminate and pistillate cones on same branches; mature cones globular, tightly closed but opening at maturity. The genus is represented by *C. thyoidei* (white cedar).

8. *Thuja,* leaves awl-shaped or scale-like; blunt and short, persistent; staminate and pistillate cones on different branches. This genus is represented by *T. occidentalis* (arbor vitæ or white cedar).

9. *Juniperus,* leaves awl-shaped or scale-like, rigid and persistent; staminate and pistillate cones on small lateral branches; mature cones small, berry-like and covered with a white bloom. This genus includes *J. communis* (common juniper), *J. sabina,* and *J. virginiana* (red cedar).

10. *Taxus,* leaves flat, rigid and irregularly two-ranked; staminate and pistillate cones axillary; mature cone berry-like, cup-shaped, globular, pulpy, red and enclosing the nut-like seed. This genus is represented by *T. canadensis* (American yew or ground hemlock).

LABORATORY EXERCISES.

Exercise. Pinus sp. Examine a branch and note the arrangement of the needles.

Examine a cross-section of a needle. Note its structure and compare with the leaf of a flowering plant.

Examine cross, radial and tangential sections of pine wood. Note the annual rings, medullary rays, resin ducts, variation in size of cells, thickness of cell walls, cell markings, etc.

Examine a male cone. Note the arrangement of the sporophylls and the position of the sporangia.

Examine some of the microspores (pollen) under the microscope.

Examine a female cone. Note the arrangement of the sporophylls and the position of the sporangia.

Examine prepared sections showing the gametophyte and the archegonia,

Examine prepared sections showing the formation of the embryo.

Examine mature cones showing the position of the mature seeds. Note the form of the seeds.

CHAPTER XXIX

MONOCOTYLEDONES

THE characters of this great division, including 25,000 species of plants, have already been given (page 304). The number of species is so great that only a few of the most important will be given at this time. One of the most prominent and best-known families is the lily family, which receives early consideration.

TYPHACEÆ.—Herbs (marsh or aquatic); perennial; flower monœcious, without floral envelopes and borne on a spadix or in heads; leaves linear. This family contains the very common and well-known cattails (*Typha latifolia* and *T. angustifolia*).

GRAMINACEÆ (Grass Family).—Herbs*; annual or perennial; stems usually hollow,† cylindrical, closed at nodes, in some cases rhizomes; roots fibrous; leaves two-ranked, alternate, parallel-veined and the basal part sheathing the stem. Flowers usually perfect, occasionally monœcious, diœcious or polygamous; inflorescence in spikelets, which are collected into spikes or panicles; perianth imperfect, occasionally wanting; stamens three or six, occasionally four, two or one; ovary superior, one-chambered, one-ovuled; styles two-, occasionally three-parted; cleistogamous or anemophilous (occasionally entomophilous); fruit a caryopsis.

This is one of the largest families and contains about 3500 species, widely distributed throughout the world and including many of our most important forage plants and grains. A few of the most important will be given special attention.

✓ The common wheat (*Triticum vulgare*) (Fig. 154) is an annual plant which is grown very extensively for the grain. The

* Shrubs or tree-like in the bamboos.

† Corn is a member of the grass family with a solid stem.

roots are fibrous, the stems hollow and closed at the nodes, the leaf of the typical grain type, the inflorescence of spikelets arranged on a spike, which is frequently referred to as the head. The axis or rachis of the spike is zigzag, the spikelet being attached on the outer or convex side of the curve and resting in the concave side next above. Each spikelet contains from two to five flowers, but usually only two grains reach maturity. Each

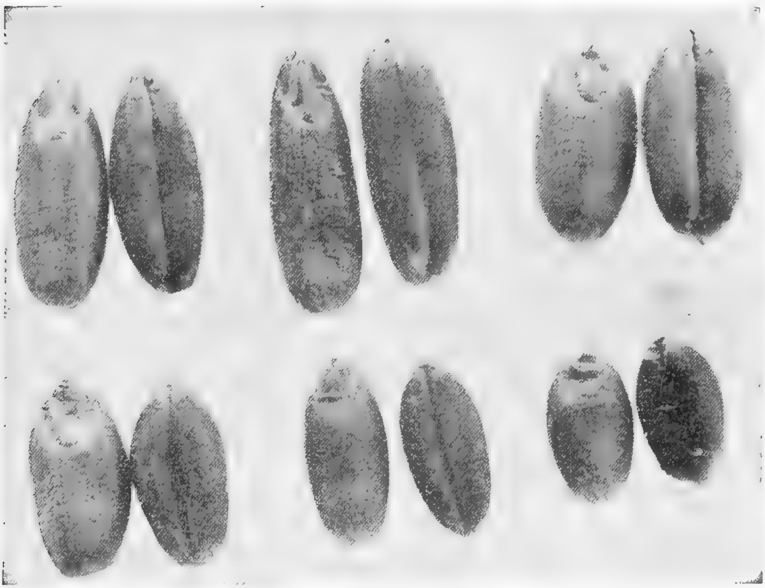


FIG. 154.—Six types of wheat. Top row, durum, Polish wheat, and white winter. Bottom row, red winter, hard winter, and hard spring. (Productive Farm Crops.)

flower consists of one pistil, with two stigmas, three stamens and two glumes (the outer or *lemma* and the inner or *palet*). The entire spikelet is enclosed between two glumes. The lemma and the palet are sometimes spoken of as fertile glumes and the two outside glumes as empty glumes.

History.—Wheat has been cultivated from a very remote period and is generally supposed to have originated in western

Asia, but this is not definitely known. It is said that the Chinese grew wheat fully 2700 B.C. and "considered it a gift direct from heaven." The ancient Egyptians and Greeks were familiar with wheat, and it was also grown in Italy and Switzerland at an early date. There is no known wild wheat that very closely resembles our cultivated varieties, but the emmer of Syria shows certain resemblances which have led some authors to consider

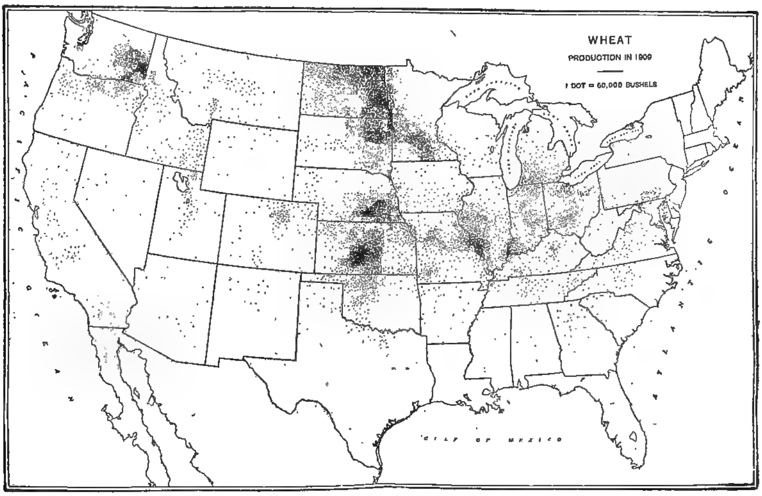


FIG. 155.—Wheat production.

it the prototype of our wheat. There are a number of species and varieties of wheat (Figs. 154, 155).

The wheat production of the United States in 1915 was 1,011,505,000 bushels. Its uses are well known.

Rye (*Secale cereale*) is an annual plant which is grown extensively as a grain. The roots are fibrous, the stems tougher, longer and more slender than that of the wheat and the leaves similar to those of the wheat. Each spikelet contains three flowers, the two outer reaching maturity and the central ones aborting. The empty glumes are narrow, the lemma broad, keeled and awned, the palet thin, blunt and keeled. There are

FIG. 156.—Rye inflorescence.

three stamens and a single ovary with two stigmas (Figs. 156, 157).

History.—Rye originated in southern Russia and in the districts north of the Black and Caspian Seas, but we have no records as to when it was first cultivated. It is now grown extensively in the colder parts of the temperate zones. In some parts of Europe it is a more important bread plant than wheat.

Barley (*Hordeum distichon*) is grown very extensively as an annual. The roots, stems and leaves are similar to those of the wheat. The inflorescence is a cylindrical spike; each spikelet is one-flowered, the glumes are narrow, the lemma broad, rounded, five-nerved and with long awn, the palet about the same length and two-nerved; three stamens and one ovary with two stigmas.

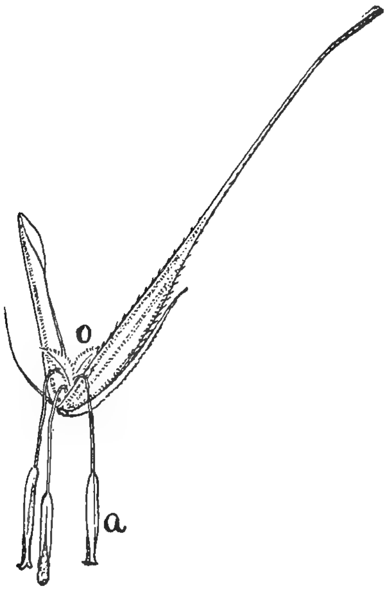


FIG. 157.—Single blossom of rye; (*a*) stamen; (*o*) pistil.

The origin of barley and its early cultivation is unknown. It is supposed to have originated in western Asia and to have spread from there into the Mediterranean region. It is now used extensively as a food plant for both man and live stock.

Oat (*Avena sativa*) is grown extensively as an annual farm crop. The roots, stems and leaves are similar to those of the wheat. The inflorescence is a panicle, each spikelet has two to five flowers; glumes two, loose, membranous and without terminal awns, the lower one usually toothed and with twisted awn on back; three stamens and one ovary with two sessile stigmas.

Oats are supposed to have originated in central Asia at a very early period in history. They are grown wherever conditions will permit and used extensively as a food for both man and live stock. The fact that it is a short-season crop makes it

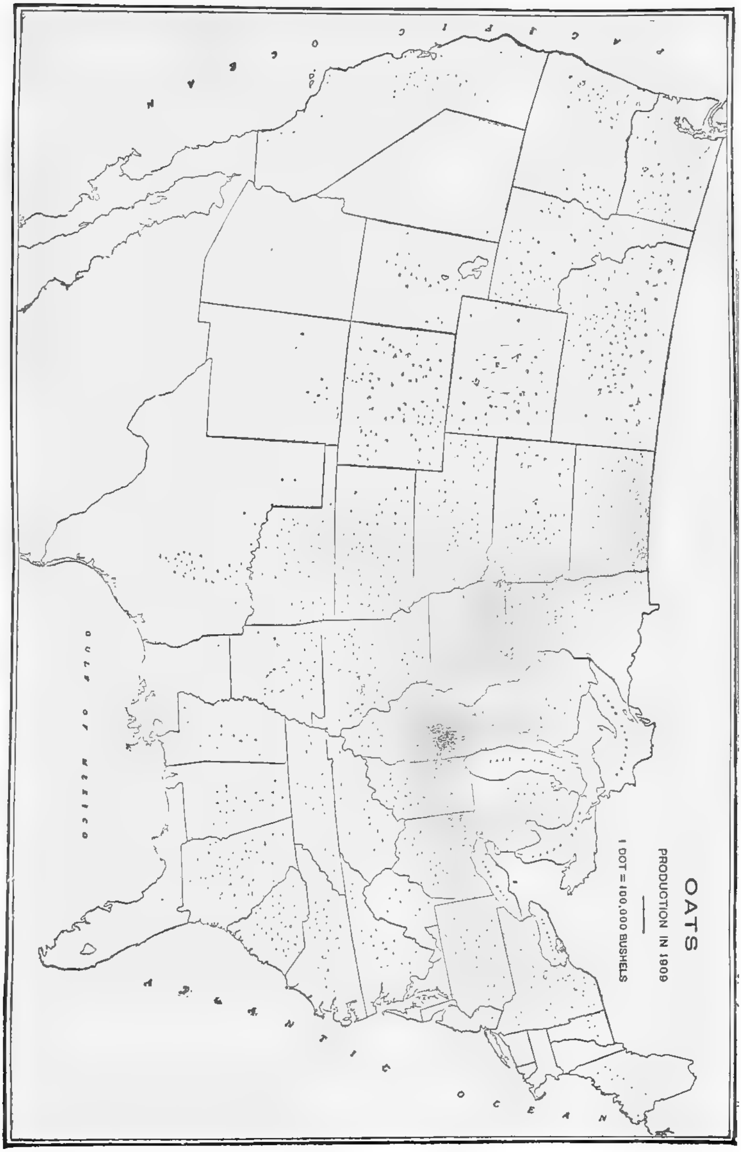


FIG. 158.—Distribution of oat production in the United States. (From U. S Census, 1910.)

possible to grow it much farther north than most grains (Fig. 158).

Rice (*Oryza sativa*) is grown extensively in Asiatic countries and to some extent in other parts of the world. It requires a warm climate and low, wet soils. The roots, stems and leaves are very similar to wheat. The inflorescence is a close compound panicle; the spikelets are flowered, glumes two and very small,

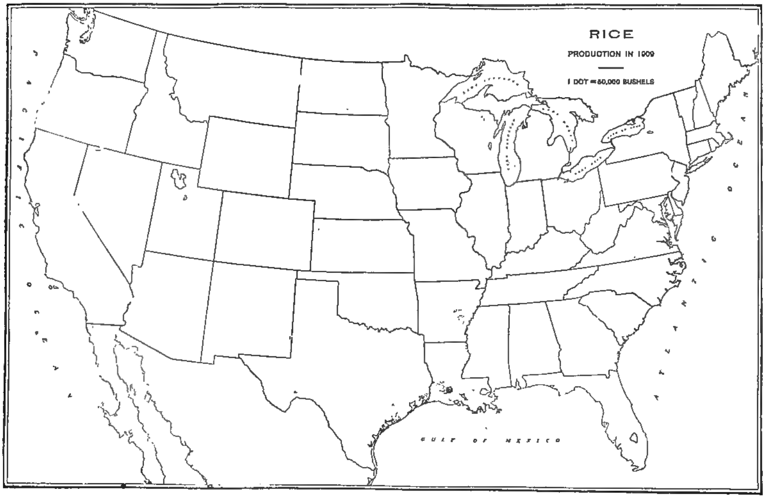


FIG. 159.—Rice production.

paleæ two, the lower one with a straight awn, six stamens and two stigmas.

We know nothing of the early history of rice other than that it was cultivated at least 2800 years B.C. It is probably used more extensively as an article of food than any other grain (Fig. 159).

Indian corn or *maize* (*Zea mays*) (Figs. 160, 161) is an American plant which is grown extensively throughout the western hemisphere and to some extent in other parts of the world.

FIG. 160.—Two ears of Indian corn; *i.e.*, the pistillate flowers.

The roots are fibrous, the stem one to two inches in diameter, three to eight or more feet in height, solid and containing numerous woody fibers which are embedded in the pith. The leaves are alternate, sheathing and strap-shaped. The inflorescence is monœcious, the staminate flowers borne at the tip of the plant in a

FIG. 161.—The tassel or staminate flowers of the Indian corn.

compound panicle called the tassel; the pistillate flowers borne in a spike or ear on the side of the stalk and covered with husks. The fruits or grain are flat, cuneate-shaped. It is grown more

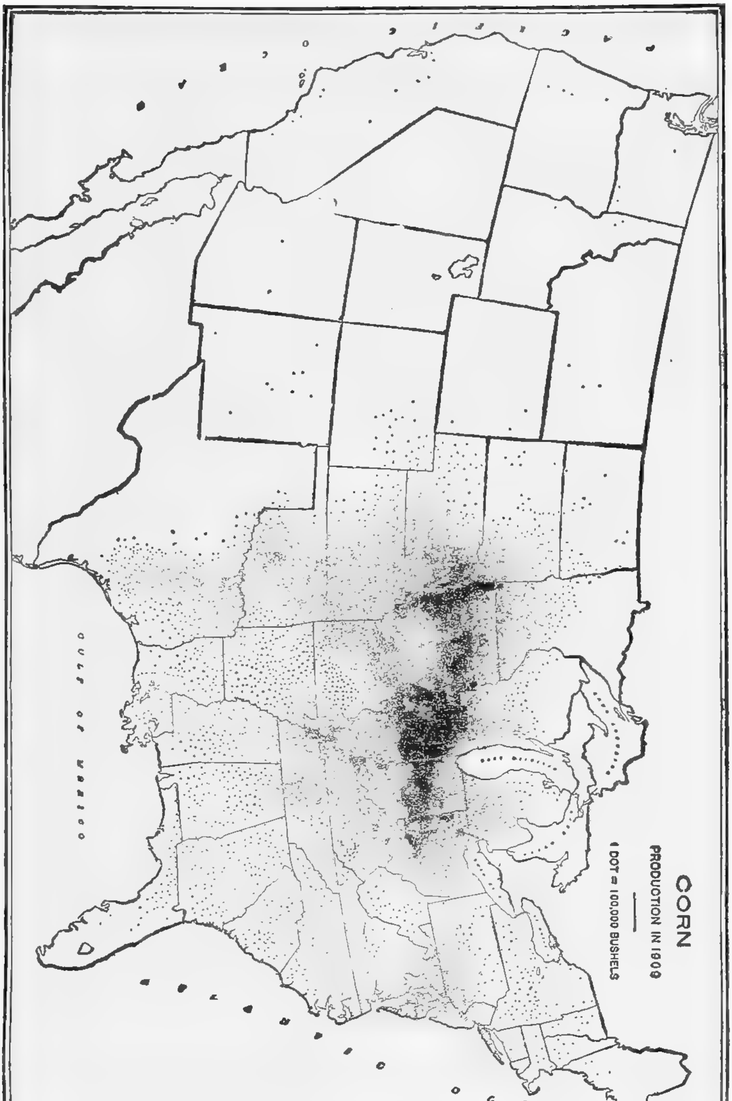


Fig. 162.—Distribution of corn production in the United States. (From the United States Census.)

extensively in America than in any other part of the world and is used in great quantities as food for both man and live stock. It is one of the most valuable of the American food plants; its only rival being the potato (page 375) which is cultivated more extensively in some parts of the world than the corn. There are a great many varieties which are suited to many varieties of soil and climate and to many uses (Fig. 162).

Sugar cane (*Saccharum officinarum*) is a plant which resembles corn in general appearance but is much taller, sometimes attaining a height of fifteen or twenty feet. The inflorescence is a terminal panicle, the spikelets are borne in pairs, of which one is pedicellate and the other sessile. Each spikelet contains two flowers and tufts of long silky hairs, the lower flower is without stamens or pistils, but the upper one is perfect, consisting of two awnless glumes, one to three stamens, single, sessile, smooth ovary with two styles and plumose stigma.

It originated in Cochin-China, but it is not known just when it was first brought under cultivation. Sugar was first used in the compounding of medicine and has been used as a food for less than 500 years. Sugar cane is grown extensively throughout the tropical regions of the world. However, it should be remembered that we now secure a considerable part of our supply of sugar from other plants, such as sugar beets and maple trees.

Broom corn (*Sorghum saccharatum*) is a plant which resembles Indian corn in general appearance, but has perfect flowers borne in a rather dense, complicated terminal panicle. It originated in central Africa but is now grown in many temperate regions and is used for the manufacture of brooms, feeding of cattle and poultry and to some extent for the making of syrup and sugar.

Millet (*Setaria italica*) has leafy stems from two to five feet in height and a close, compound spike inflorescence. Its origin is somewhat uncertain. It is grown in many parts of the world for stock feed, and the seeds are very generally used as feed for caged birds.

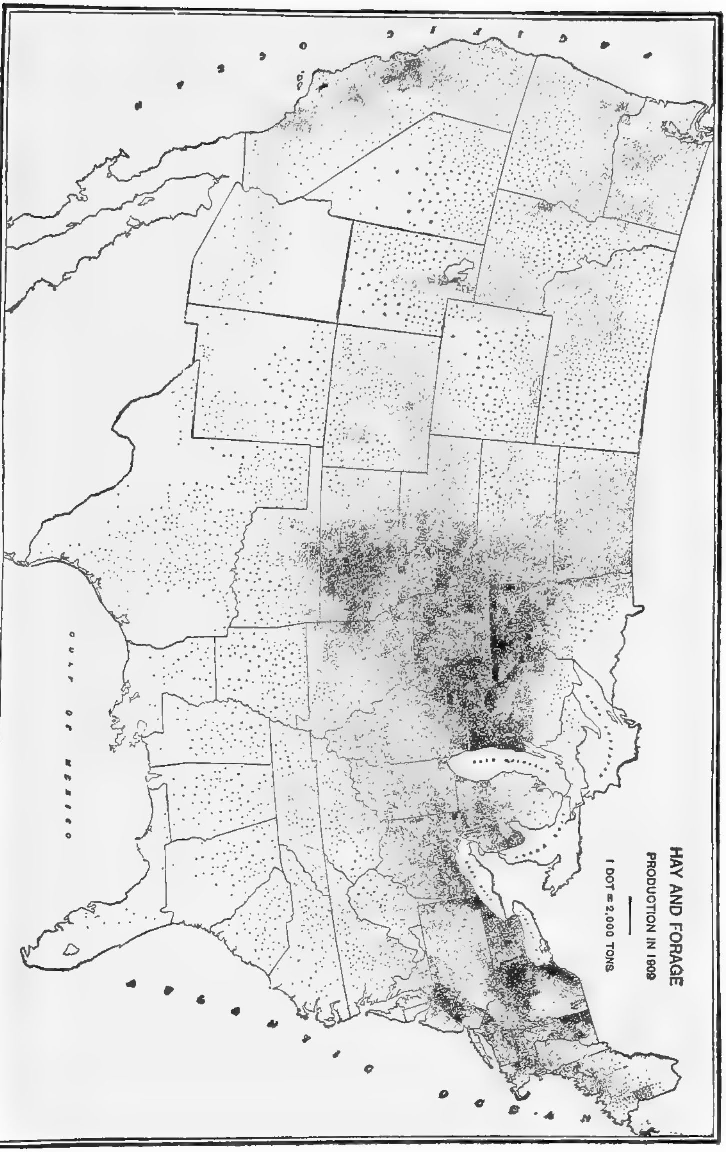


FIG. 163.—Distribution of forage crops in United States. (From U. S. Census Report, 1910.)

There are a great many other grasses, many of which are of great agricultural value. Among the most important are timothy (*Phleum pratense*), the orchard grass (*Dactylis glomerata*) and

FIG. 164.—Cyperaceæ

the blue grass (*Poa pratensis*). There are also many grasses which are great annoyances to the farmer and may be classed as weeds (Fig. 163).

CYPERACEÆ (Sedge Family).—Herbs which are grass-like or rush-like in character; stems usually solid; leaves threeranked, sheathing and parallel-veined; roots fibrous; inflorescence spiked; flowers usually three-androus; axillary in the glume-like bracts; no perianth; ovary one-chambered; style two-cleft; fruit three-angled.

A very large and widely distributed family, most of the species of little or no economic importance. Some few are used in manufacturing and some few as ornamentals (Fig. 164).

FIG. 165.—Lily blossom. A polypetalous flower.

BROMELIACEÆ.—Herbs; mostly tropical or subtropical and mostly epiphytic; flowers perfect, usually regular, three-merous, and borne in racemes or panicles; fruit a three-seeded berry or capsule. This family includes the pineapple (*Ananassa sativa*) and the southern moss (*Tillandsia usneoides*). This may be considered a strictly American family and the well-known pineapple is its most valuable species and is now cultivated in most tropical countries.

Liliaceæ (Lily Family).—Herbs or occasionally woody plants; perennials; underground parts bulbous, tuberous or a

Fig. 166.—Dog-toothed violet (*Erythronium americanum*), a type of the lily family.

rhizome; flowers regular, perfect, symmetrical, usually terminal, solitary, racemes or spiked; perianth tubular and inferior; six stamens attached to the receptacle or to the perianth tube; ovary free, superior, and three-chambered; few to many seeds in each chamber; style simple or three-cleft; fruit a capsule or berry; leaves simple, entire and sessile (Figs. 165 and 166).

The members of this family are widely distributed throughout the world, especially in the temperate zones. The family contains a number of ornamental plants and a few cultivated vegetables.

The onion (the genus *Allium*) includes a number of species and varieties which are of commercial importance. The common onion is *A. cepa*. The valuable part of this plant is the well-developed bulb made up of a short conical stem to which are attached numerous sheathing leaves with thickened bases. The terminal bud sends up a long hollow or sometimes solid, leafless stem which bears an umbel inflorescence. Some species produce numerous bulbs at the apex of this stem. A mass of fibrous roots is developed from the lower end of the stem. The flower is regular, perfect and consists of a six-parted perianth, six stamens and a single superior ovary. The pollination is by means of insects. The fruit is a three-chambered membranous pod or capsule. Two black seeds are borne in each capsule.

This genus includes about 250 species, mostly in North America and in northern Europe.

History.—The common onion is probably a native of southwestern Asia and has been cultivated for so long that its early history is lost. During this long period of development many commercial varieties have appeared.

Other Important Species.—Garlic (*A. sativum*) is a European perennial herb; Leek (*A. porrum*) is a biennial which is a native of the Mediterranean districts of Europe; Chives (*A. schœnoprasum*) is a perennial which is grown extensively in both the old and the new world; the field garlic or wild onion (*A. vineale*) is a European plant which has been introduced into the United States and has become a very troublesome weed.

Uses.—Onions and other species of this genus are most extensively used as vegetables, for flavoring and for pickling. The allyl sulphide is said to stimulate the flow of digestive juices and therefore they are sometimes recommended to correct troubles of the alimentary tract. Owing to their low sugar and starch content, they are sometimes recommended for invalids who cannot use starchy foods.

The genus *Asparagus* includes the very important vegetable of that name and a number of ornamental species. The common edible asparagus (*A. officinalis*) has both underground and aerial stems and fibrous roots. The early spring shoots are very fleshy and are used extensively for food, while the later shoots are allowed to grow and produce flowers and fruits. The small scales on the stems are true leaves, but clusters of filiform structures, known as *cladophylls,* are produced in the axils of these scale leaves and function as leaves.

The flowers are small, solitary, axillary, perfect with a six-parted perianth, six stamens inserted on perianth, ovary three-angled, style short, stigma three-parted, the fruit a red globose berry of three chambers and two seeds in each chamber, pollination by means of insects.

The origin of the common asparagus is not definitely known, but it was used as a vegetable by the Greeks and Romans at least 2000 years ago. It is widely distributed throughout the temperate zones of the world and has escaped from cultivation in many places.

Asparagus is a very common vegetable, and is very popular because it comes so early in the spring. It is grown extensively throughout the country.

The genus *Smilax* includes a number of species, some of which are important as ornamentals, and some of which furnish the sarsaparilla of commerce which is used in flavoring and as a drug.

Sarsaparilla is obtained from species growing in Mexico, Central America and the northern part of South America. It became very prominent in the treatment of blood diseases about the middle of the sixteenth century, but its value was overestimated and it is no longer considered of much importance.

Among the most important ornamentals are the many species and varieties of lilies, tulips, hyacinths, trilliums and lilies of the valley.

AMARYLLIDACEÆ.—Herbs, mostly bulbous; flowers perfect, regular, three-merous and lily-like; fruit a three-chambered, many-seeded capsule; leaves linear. This family includes many interesting flowering plants, such as the Narcissus, Daffodil, Snowdrop, star grass and the American Agave or Century Plant.

The genus *Aloe* includes many tropical and semi-tropical, old world species, some of which are cultivated in America. They furnish an important drug and some species are also valuable for fiber. The American Aloe (*Agave americana* L.) was cultivated in Mexico long before the coming of the white man. It is grown for its fiber and also for the making of pulque, a very strong alcoholic liquor.

IRIDACEÆ.—Herbs; flowers regular or irregular, perfect, solitary or in a terminal spike or corymb or loose panicle, three-merous; ovary inferior; fruit a three-angled, three-chambered, many-seeded capsule; leaves linear, two-ranked, equitant.

The most conspicuous member of this family is the "flower-de-luce" or iris, which is grown extensively for ornamental purposes. Another well-known species is the crocus (*Crocus sativus*), which is grown extensively as an ornamental and for saffron, which is used to color and flavor confectionery and as a commercial dye.

ORCHIDACEÆ.—Herbs; perennial, sometimes tuberous; sometimes epiphytic; flowers irregular, perfect, six-merous; ovary one-chambered, three-parietal placentæ; ovules numerous; stamens one- or two-gynandrous; pollen in a more or less sticky mass. Fruit a one-chambered, three-valved capsule; seeds very small and numerous; leaves alternate and parallel-veined.

This family contains more than 7000 species which are mostly tropical. Many of them are remarkable for their most beautiful flowers. Many of the flowers are especially adapted for pollination by certain insects. One tropical American genus (*Vanilla*) contains two species from which the vanilla of commerce is obtained. Many other species are grown because of their great beauty. This family is represented in our north temperate zone by a great many species. The genus Cypripedium, which includes the lady's slipper or moccasin flower, is one of the best known.

CHAPTER XXX

DICOTYLEDONOUS PLANTS

THE characters of this great division have already been given (page 304). It includes 100,000 or more species and therefore we can do little more than mention a few of the most important.

SALICACEÆ (Willow Family).—Trees or shrubs; leaves alternate and stipulate; both kinds of flowers in catkins; stamens one to five, or more; pistil one-chambered and two- to four-valved; fruit a dry capsule containing numerous seeds, each furnished with a silky down. Wood soft and light. Only two genera but many species.

The genus *Salix* contains the many species of the willows and the genus *Populus* contains the poplars and cottonwoods.

JUGLANDACEÆ (Walnut Family).—Trees; leaves alternate, pinnately compound and without stipules; inflorescence, staminate flowers in catkins, pistillate flowers axillary; stamens three to forty inserted on base of bract; ovary two- to four-chambered; styles two; fruit a drupaceous nut. A small family restricted to temperate climates.

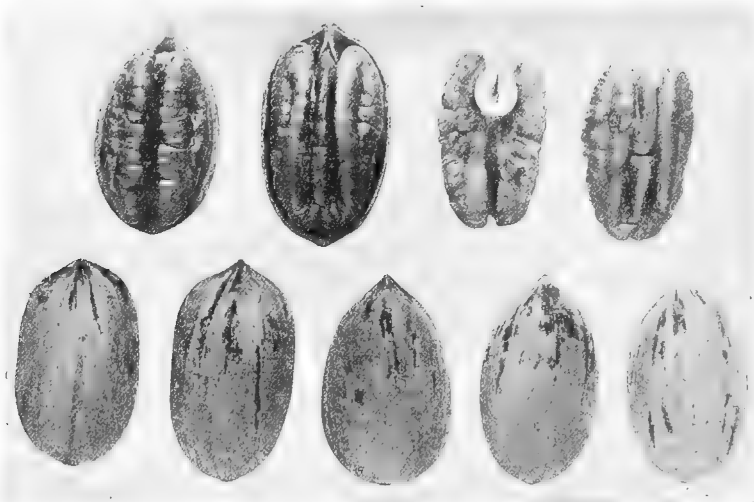
The American black walnut (*Juglans nigra*) and white walnut or butternut (*J. cinerea*) are well-known trees which are prized for their nuts; the former is one of the most valuable of our American woods. The so-called English walnut (*J. regia*) is in reality a Persian walnut which is grown extensively in California for its nuts and for its wood.

The American hickories (*Hicoria* or *Carya*), of which there are many species, are well-known trees which are valued both for their wood and nuts. The pecan (*H. olivæformis*) is grown for its nuts, which are of very great commercial value (Fig. 167).

BETULACEÆ.—Trees or shrubs; simple, alternate leaves with deciduous stipules; staminate flowers in catkins; pistillate flowers in clusters, spikes or catkins; fruit a one-seeded nut, with or without involucre.

This family includes the hazelnuts and filberts (*Corylus*), the ironwoods (*Ostrya virginiana* and *Carpinus caroliniana*), many species of birch (*Betula*), and alders (*Alnus*).

Fagaceæ.—Trees or shrubs; simple, alternate leaves with deciduous leaves; staminate flowers in catkins or capitate clus-



(Fig. 167.—Pecan nuts showing one of the many forms grown for market. (U. S D. A.

ters; pistillate flowers solitary or slightly clustered; fruit a one-seeded nut, partly or completely enclosed in an involucre.

This family includes the beech (*Fagus ferruginea*), the chestnut (*Castanea dentata* (Fig. 168) and *C. pumula*) and a very large number of species of oaks (*Quercus*). Most of these plants are highly valued for their woods; the beech and chestnuts for their nuts; and the oaks for their acorns.

Urticaceæ (Nettle Family).—Trees, shrubs and herbs; leaves alternate and stipulate; inflorescence axillary; flowers monœcious, diœcious or rarely perfect; calyx regular; stamens (when present) equal in number to the lobes of the calyx and opposite them; ovary one-chambered, one-capsuled; fruit an achene or a drupe, sometimes many fruits united into a mass. A large family of diversified characters, mostly tropical.

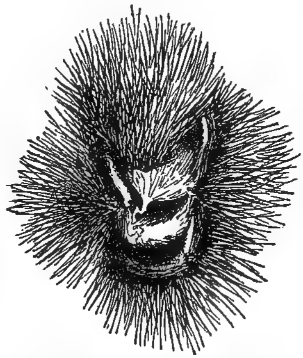


FIG. 168.—Bur of native chestnut showing two seeds within. (Productive Plant Husbandry.)

The elms (*Ulmus*), of which there are several species, are good types of this family in which the fruit is developed as a samara (Fig. 169). The American hackberry (*Celtis occidentalis*) is another familiar American tree; the common hop (*Humulus lupulus*) is a well-known vine which is grown to some extent for its bitter and aromatic principles.

The American red mulberry (*Morus rubra*) and the Asiatic

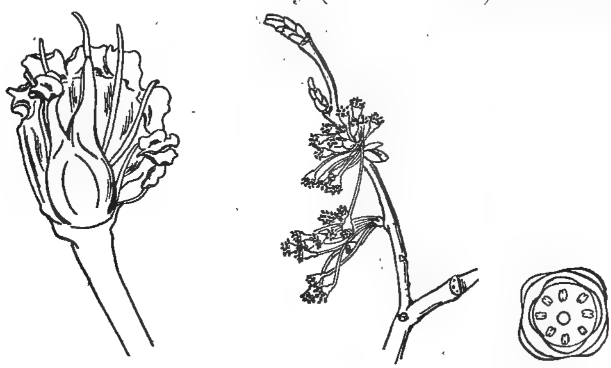


FIG. 169.—Flower of elm.

white mulberry (*M. alba*) are well-known fruits. The silkworms feed upon the leaves of the latter, which is grown extensively for that purpose (Fig. 170).

FIG. 170.—Fruit of mulberry.

FIG. 171.—Fig.

FIG. 172.—Buckwheat.

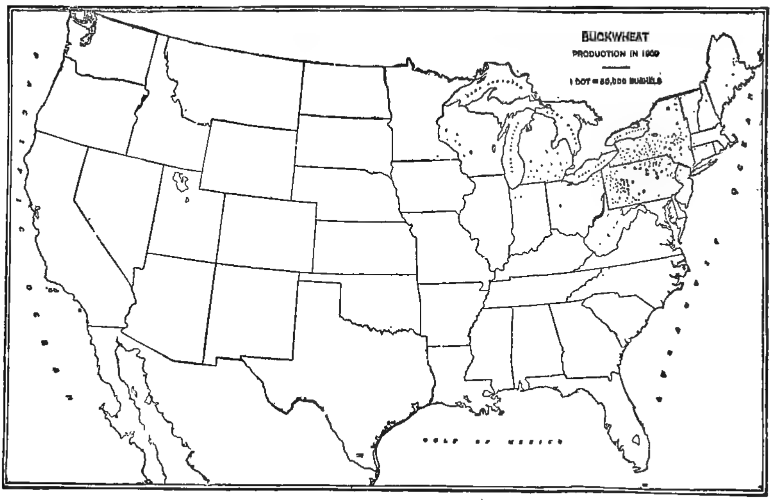


FIG. 173.—Distribution of buckwheat in United States. (U. S. Census, 1910.)

The fig (*Ficus sarica*) (Fig. 171), the rubber plant (*F. elastica*), the banyan tree (*F. bengalensis*), and the hemp (*Cannabis sativa*) belong to this family.

POLYGONACEÆ (Buckwheat Family).—Herbs; stems with swollen joints; leaves alternate with sheathing stipules; flowers perfect (or polygamous); calyx three- to six-cleft and more or less persistent, the inner circle sometimes petaloid; stamens one to nine (sometimes more); ovary one-chambered with two or three styles; fruit a one-celled, three- or four-angled or sometimes winged achene.

FIG. 174.—The table beet.

The common buckwheat (*Fagopyrum esculentum* and other species) (Figs. 172, 173) is a native of Asia which has been widely distributed throughout the world.

The rhubarb or pie-plant (*Rheum rhaponticum* and other species) is a well-known garden plant which probably originated in Asia. It is also used in medicine.

This family also includes the common docks and sorrels (*Rumex* sp.), the grass or smartweeds (*Polygonum* sp.) and a number of other familiar plants.

CHENOPODIACEÆ (Goosefoot Family).—Mostly herbs; leaves alternate; inflorescence in spikes; flowers small and greenish; calyx five-cleft and persistent; stamens five or less; ovary depressed, enclosed in the calyx; one-chambered, one-seeded; styles two (occasionally more); fruit a utricle or occasionally an achene. A large but not very pleasing family containing many weeds and two vegetables.

The common garden beet (*Beta vulgaris*) (Fig. 174) is a native of the Mediterranean regions and was used 500 years or more before the Christian era. Two varieties of it are the

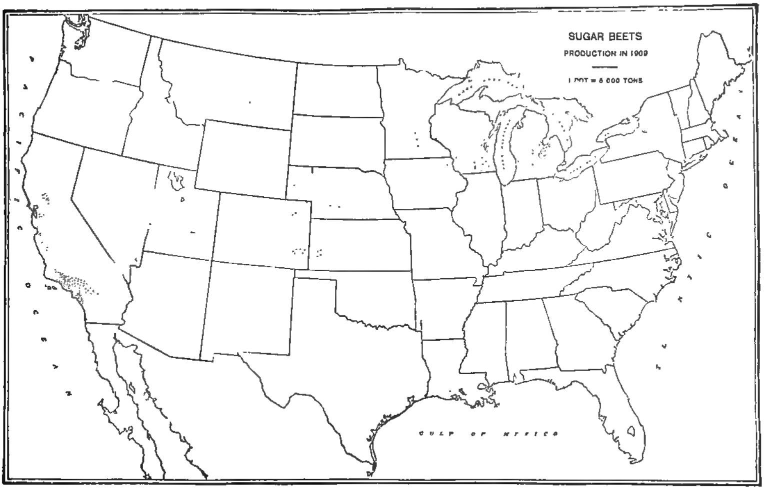


FIG. 175.—Sugar-beet production.

sugar beet, that is grown extensively for the manufacture of sugar (Fig. 175), and the mangel-wurzel, that is grown extensively for stock feed.

Spinach (*Spinacia oleracea* Linn.) was first known in Europe in the sixteenth century. Its early history is unknown, but it probably originated in Persia and found its way into other parts of Asia long before it was generally known in Europe.

NYMPHÆACEÆ.—Herbs; aquatic, perennial and growing from horizontal root stocks; flowers perfect and usually showy;

leaves floating or immersed. This family is represented by the well-known water lilies.

RANUNCULACEÆ.—Herbs, occasionally woody plants; leaves frequently dissected; flowers regular or irregular; polypetalous or apetalous; calyx often colored; stamens numerous; pistils few to many (occasionally single).

This family includes many of our early spring flowers and many ornamentals. Some of the most common are the buttercup, the hepatica, anemones, clematis, columbine and larkspur.

FIG. 176.—Barberry.

MAGNOLIACEÆ.—Trees or shrubs; flowers perfect; calyx and corolla colored alike and in three or more rows of three parts each; pistils many and usually closely packed, covering the elongated receptacle and forming a dry or somewhat fleshy, cone-like fruit; leaf buds covered by membranous stipules. This family includes the Magnolias, which are grown so extensively because of their beautiful flowers, and the tulip tree (*Liriodendron tulipifera*), which is a very valuable forest tree.

ANONACEÆ.—Trees or shrubs; flowers axillary, solitary, perfect and three-merous; fruit very fleshy and containing many large seeds. This family contains many very valuable tropical fruit-producing plants. It is represented in the north temperate zone by the American papaw (*Asimina triloba*).

BERBERIDACEÆ (Barberry Family).—Shrubs or perennial herbs; leaves alternate; flowers regular, usually three-merous; sepals and petals imbricated in the bud; stamens as many as the petals and opposite them; anthers opening by hinged valves; pistil single; style short; fruit a berry or pod.

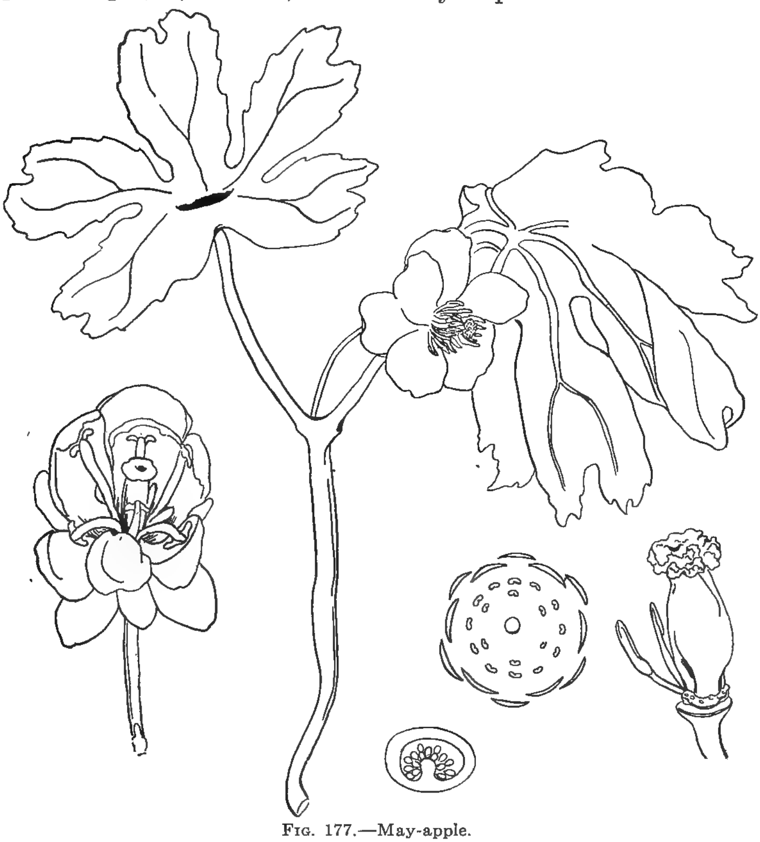


FIG. 177.—May-apple.

This includes the common barberry (*Berberis vulgaris*) (Fig. 176), which has been introduced from Europe, a shrubby, thorny plant bearing flowers and fruits in racemes. It is used extensively for ornamental purposes but is in bad repute because it bears the æcial stage of the rust fungus (*Puccinia graminis*), which attacks the wheat, oats, grasses and related plants.

Berberis thunbergii is the Japanese species of barberry which is used extensively throughout the country as an ornamental shrub. It is smaller, more compact and more beautiful than the *B. vulgaris* and is immune to the rust.

The may-apple or mandrake (*Podophyllum peltatum*) (Fig. 177) belongs to this family and is a familiar plant. The upright shoots grow from an underground stem and bear the large umbrella-like leaves and solitary white flowers. It is used to some extent in medicine.

LAURACEÆ (Laurel Family).—Trees or shrubs; flowers regular and in clusters; fruit a one-seeded berry or fruit; leaves simple and alternate. This family is represented by the well-known Sassafras tree (*Sassafras officinale*) and the allspice or spice bush (*Lindera benzoin*).

PAPAVERACEÆ (Poppy Family).—Herbs, with milky, sometimes colored juice; roots fibrous, stems underground or aerial; leaves alternate and without stipules; flowers regular, terminal, sometimes solitary, with parts in two or four; sepals usually two, falling early; petals four to twelve, imbricated, falling early; stamens numerous; pistil style syncarpous, by union of the carpels, short; stigma two or more; fruit a dry capsule.

The family includes the poppies (*Papaver*), of which there are many species. One of the most important is *P. orientale*, from which the opium and morphine of commerce are obtained. The medicinal value of this plant for producing sleep and relieving pain was known fully 400 years B.C. In more recent times its use as a narcotic became so great that it has been necessary to restrict its cultivation and most countries have vigorous laws for the control of its sale and use. There are several other species of poppy which are used extensively as ornamentals. This family also includes our American bloodroot (*Sanguinaria canadensis*) and other of our native wild flowers.

Cruciferæ (Mustard Family).—Herbs, with a pungent or peppery juice; stems cylindrical or angular; leaves alternate and without stipules; inflorescence in terminal racemes or co-

Fig. 178.—Flower of Cruciferæ.

rymbs; flower perfect, usually white or yellow; sepals four; petals four, forming a cross; stamens four long and two short (rarely four or two); ovary two-chambered; stigmas two; fruit a many-seeded capsule. A very large family containing many economic plants (Fig. 178). Some of the more important are as follows:

The genus *Brassica* contains *B. nigra* (black mustard), *B. alba* (white mustard), *B. oleracea* (cabbage), *B. campestris* (field turnip), *B. rapa* (flat turnip) and *B. napus* (rape).

The cultivation and use of mustard was known by the Greeks and Romans fully 300 years B.C. and traveled with the spread

FIG. 179.—The spherical form of cabbage.

of Christianity into other parts of Europe and thence throughout the world. It is used extensively as a condiment for dressing foods, in the making of soaps and for medicinal purposes.

The cabbages have been derived from the wild cabbage (*B. oleracea*) (Fig. 179) of central and western Europe, but are now grown throughout the greater part of the world. It was used as food for at least 300 years B.C. Among the most important are the common head cabbage (var. *capitata*), the Brussels sprouts (var. *gemmifera*), the Kohl-rabi (var. *caulo-rapa*) (Fig. 180), and the cauliflower (var. *botrytis*) (Fig. 181).

FIG. 180.—Kohl rabi of edible size.

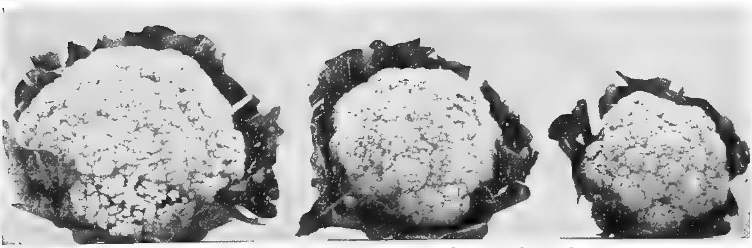


FIG. 181.—Cauliflower, with outer leaves trimmed

The turnips (Fig. 182) are of very ancient origin and probably came from Europe but were not very extensively used previous to the seventeenth century. They are now grown throughout a considerable part of the world, especially the north temperate zone, and are used as a vegetable and for stock feed. There are three important species, as indicated above, and many varieties. The rape is grown because of the abundant top and is used as a pasture plant for sheep, hogs and cattle. The seeds are also used as a source of oil.

The radish (*Raphanus sativus* Linn.) is a well-known early vegetable which probably originated in China, but its early history is unknown. It is extensively cultivated throughout the world, especially in temperate regions.

The horse-radish (*Cochlearia armoracia* Linn.) is another well-known vegetable which is used as a condiment. Its early history is unknown, but it probably originated in eastern Europe and western Asia.

Nasturtium officinale or water-cress is a well-known salad plant. This family also includes many wild plants, some of which are well known as weeds. Among the most common are the following: Pepper roots (*Dentaria* sp.), the whitlow grasses (*Draba* sp.), the shepherd's purse (*Capsella bursa-pastoris*) and the pepper grasses (*Lepidium* sp.).

Saxifragaceæ (Saxifrage Family).—Herbs or shrubs; leaves alternate or opposite, usually without stipules; flowers perfect and usually regular; sepals four or five; petals four or five, inserted on the calyx; stamens ten, many (rarely five) and inserted on the calyx; ovary compounds, inferior or partly inferior; fruit a two- to many-celled capsule or true berry.

The most important economic plants of this family are the currant and gooseberry, both belonging to the genus *Ribes*. The most important of our cultivated gooseberries (Fig. 183) and currants came from Europe. However, there are many ornamental plants, such as mock orange and hydrangea, belonging to this family.

HAMAMELIDACEÆ.—Shrubs or trees; flowers in heads or spikes; the calyx united with the base of the ovary; fruit a

FIG. 182.—The flat form of true turnip with white flesh.

woody, two-chambered capsule with a single bony seed in each chamber; leaves simple and alternate with deciduous stipules.

This family is represented by the witch-hazel (*Hamamelis virginiana*) and the sweet gum tree (*Liquidambar styraciflua*).

ROSACEÆ (Rose Family).—Herbs, shrubs and trees; leaves alternate and stipulate; inflorescence terminal, usually a corymb, cyme or umbel; flower perfect and regular; sepals five (sometimes three to five or eight), united at the base; petals same number as sepals (sometimes absent); stamens numerous, inserted with petals on disk of calyx tube; pistil apocarpous with one to

FIG. 183.—Gooseberry.

many carpels, distinct or united with the calyx tube; fruit a pome, drupe, follicle or achene; a large family containing many of our most important fruits and some of our best ornamentals. Owing to its diverse character we will divide it into sub-families:

Sub-Family—*Roseæ* (Roses).—Ovaries enclosed in the calyx tube, pistils of several carpels, each developing into hard, long achenes within the globose or urn-shaped, fleshy calyx-tube.

This includes the genus *Rosa,* which contains our well-known roses that are used so extensively for ornamental purposes. The growing of roses is a very important industry.

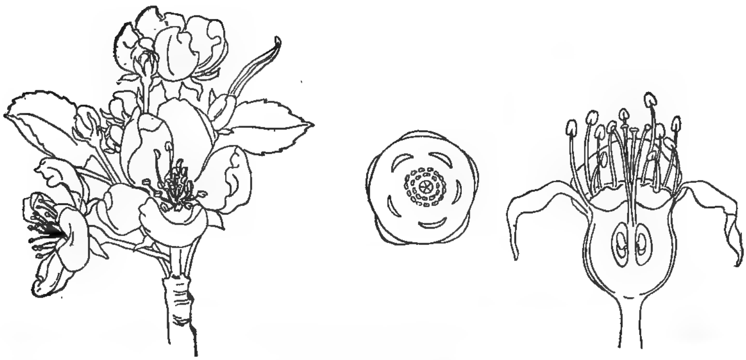


FIG. 184.—Apple.

FIG. 185.—Apple, with section showing structure of seed cases.

Sub-Family—*Pomeæ* (Apples, Pears, Quinces).—Ovaries inferior or enclosed in the urn-shaped calyx-tube; carpels two to five, enclosed in the fleshy calyx; fruit a two- to several-chambered pome (Fig. 184).

This includes the genus *Pyrus* which contains the apple (Fig. 185) and pear. The apple (*P. malus*) is supposed to have

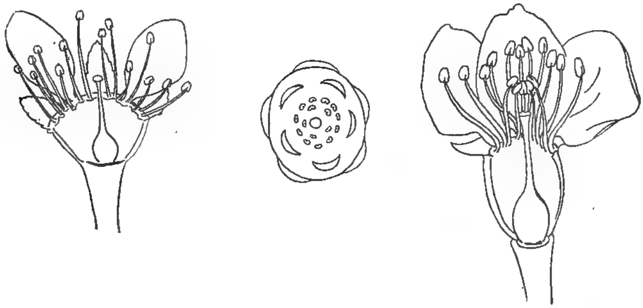


FIG. 186.—Peach.

originated in Asia and was well-known before the Christian era.

It is very generally believed that all our cultivated varieties

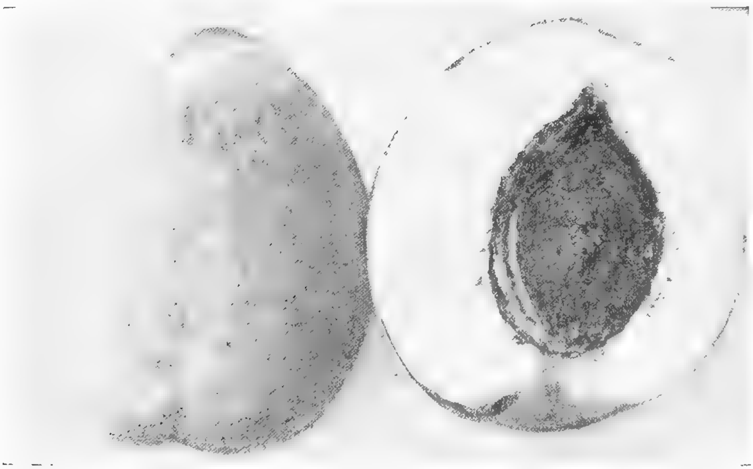


FIG. 187.—Peach, an example of the stone fruits. The plum and cherry are other examples.

were derived from the crab-apple. A very large number of varieties are cultivated, especially in the north temperate zone, and it may be considered as the most important of all fruits.

The pear (*P. communis*) is a native of Europe and was used by the ancient inhabitants. The quince (*P. cydonia*) is a native of Asia and was well known to the ancient Greeks and Romans. Both of these fruits are very generally grown throughout the north temperate zone.

The various species of American hawthorns (*Cratægus*) and of June berries (*Amelanchier*) belong to this sub-family.

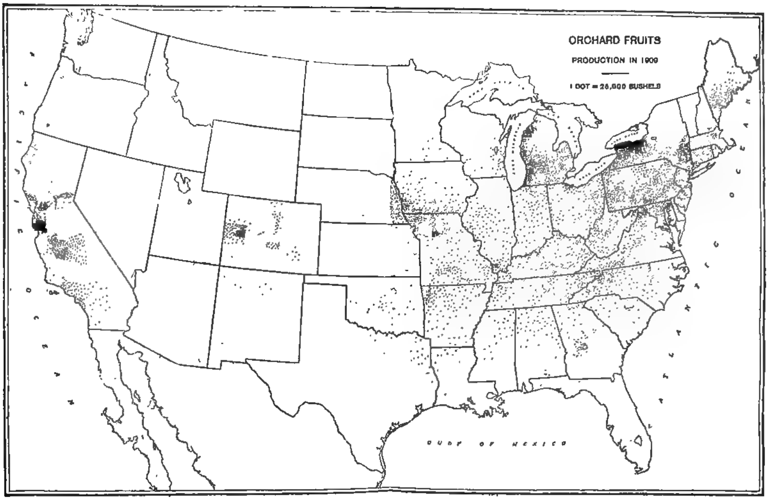


FIG. 188.—Orchard production.

Sub-Family—*Pruneæ* (Peaches, Plums, Cherries).—Ovary superior; pistil solitary; fruit a drupe (Figs. 186, 187).

This includes the many varieties of the common peach (*Prunus persia*), which is of very ancient origin and is a native of Persia or China or probably of both. It is one of the most valuable fruits grown in America. This sub-family also includes the almond (*Amygdalus* or *Prunus*) (*P. communis* and *P. nana*); the apricot (*P. armeniaca*); the many species and varieties of both European and American plums, and the many species and varieties of European and American cherries (Fig. 188).

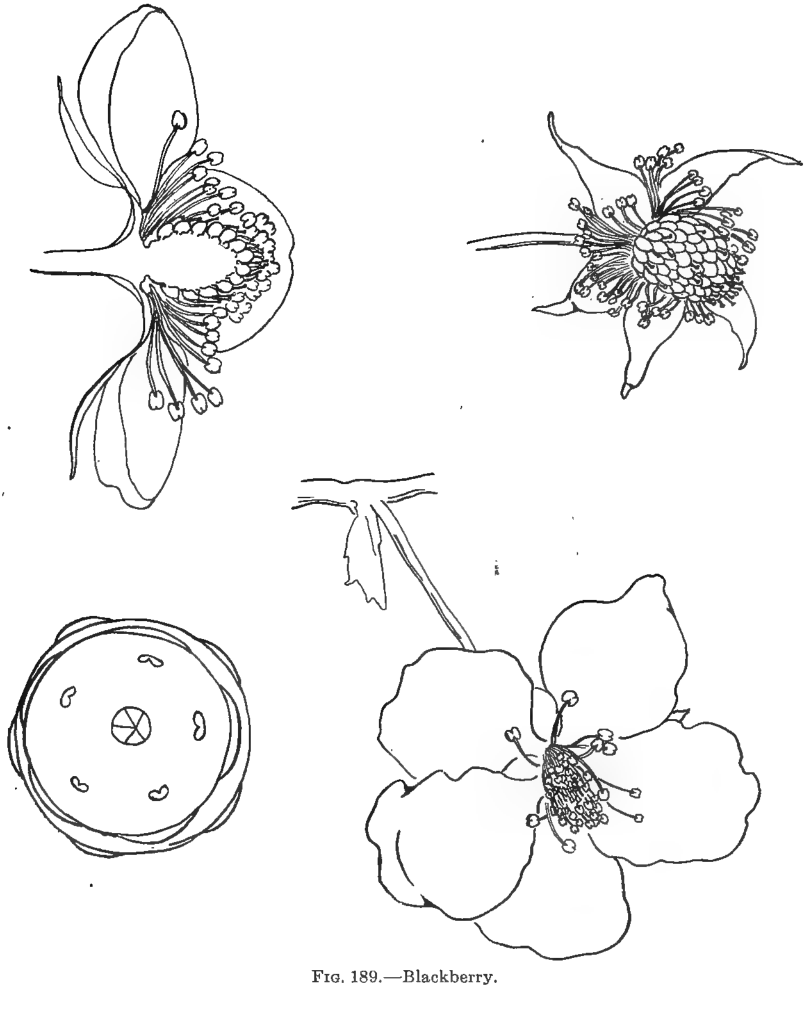


FIG. 189.—Blackberry.

Sub-Family—*Rubeæ* (Blackberries, Dewberries and Raspberries).—Ovaries superior, numerous, forming compound drupaceous fruits.

The genus *Rubus* includes the many species and varieties of the blackberries, dewberries and raspberries (Figs. 189, 190).

Sub-Family—*Potentilleæ* (Strawberries).—Ovaries superior, carpels few to many, becoming dry achenes; fruit a mass of dry achenes or a pulpy receptacle, bearing minute, dry achenes.

FIG. 190.—Blackberry, a form of aggregate fruit.

The genus *Fragaria* includes the many species and varieties of the strawberry (Figs. 191, 192, 193).

LEGUMINOSÆ (Pea or Pulse Family).—Herbs, shrubs and trees; leaves alternate, stipulate, compound, rarely simple; flowers perfect, regular or irregular; sepals five, more or less united; asymmetrical; petals five, usually more or less united, asymmetrical; stamens ten (sometimes five), monadelphous, diadelphous (or rarely distinct); pistil of one carpel and superior; ovary single. A very large family, containing many of our most valuable agricultural plants (Fig. 194).

FIG. 191.—Strawberry.

The common garden pea (*Pisum sativum*), of which there are many varieties, is well known and may be considered a type of the family. The origin of the pea is not definitely known, but it is extensively cultivated throughout a considerable part of the sub-tropical and temperate zones. The field pea (*P arvense*), which is most important as a stock feed, grows wild in Italy.

Some authors consider *P. sativum* to be a variety of the *P. arvense*, but this is doubted by others.

The common bean (*Phaseolus vulgaris*) and the lima bean (*P. lunatis*) (Fig. 195) are also well known. There are a great many cultivated varieties.

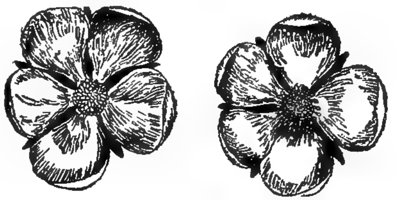


FIG. 192.—Flowers of strawberries. Pistillate or imperfect at left. Perfect at right. (Productive Farming.)

There is considerable difference of opinion as to the origin of the bean. Many claim that it came from Asia, but others believe that it is a South and Central American plant which was carried to Europe by the Spaniards at a very early date (Fig. 196).

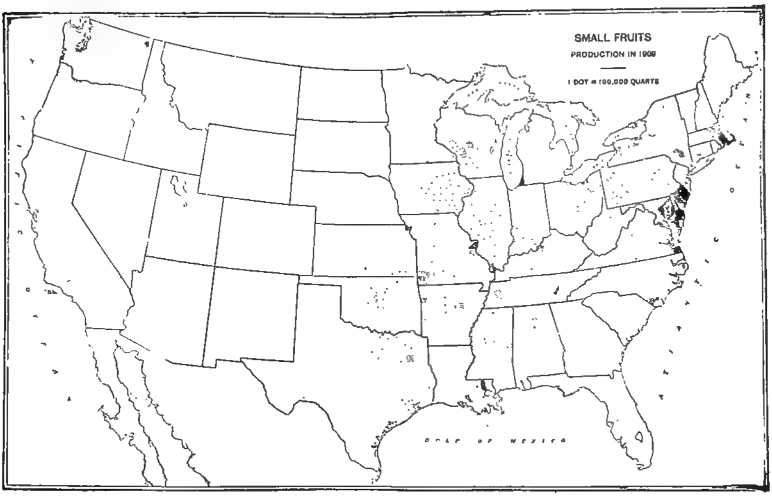


FIG. 193.—Small fruit production.

The clovers which are used so extensively as forage crops belong to this family. Among the most important are the white clover (*Trifolium repens*), the alsike clover (*T. hybridum*), the crimson or scarlet clover (*T. incarnatum*), the red clover (*T. pratense*) (Figs. 197, 198).

This family also includes many more important forage plants, such as alfalfa (*Medicago sativa*) (Fig. 199), the sweet

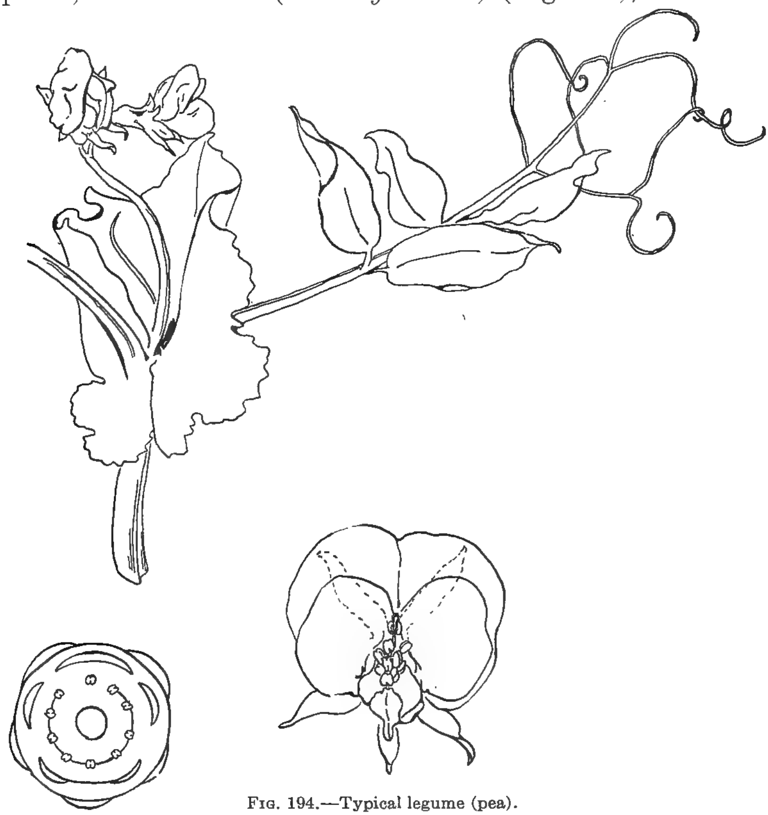


FIG. 194.—Typical legume (pea).

clovers (*Melilotus alba* and *M. officinalis*), the soy bean (*Soja max* and *varieties*) the cow-pea (*Vigna sinensis* and varieties) and the vetches (*Vicia* sp.).

The peanut (*Arachis hypogaæ*) (Fig. 200) is a very popular plant which is cultivated for food and also for the very excellent

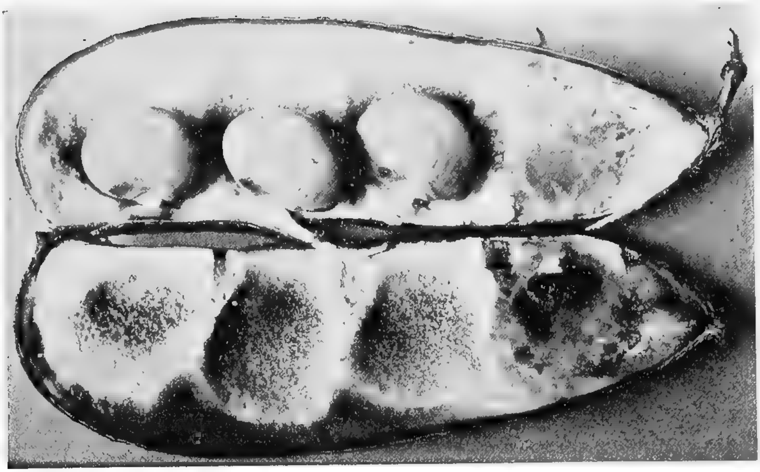


FIG. 195.—Pod and seeds of lima bean.

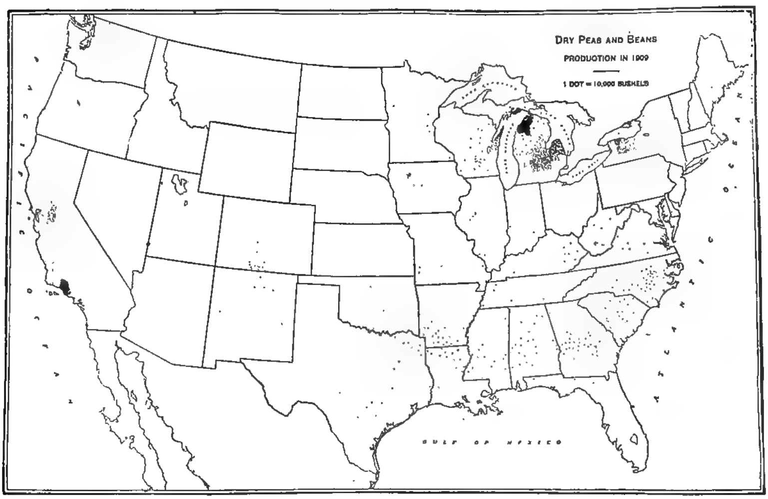


FIG. 196.—Dry peas and beans production.

oil which is used for many purposes. It is an American plant and probably came from Peru or east and central Brazil.

This family also includes the following important economic plants: the indigo plant (*Indigofera tinctoria* and other species), the milk vetch (*Astragalus gummifer*) from which gum traga-

Fig. 197.—Clover.

canth is obtained, the lentils (*Lens esculenta*), and the liquorice (*Glycyrrhiza glabra*).

This family also includes many ornamentals, such as the sweet pea, lupins, wistaria and red-bud; several trees, such as the locust (*Robinia pseudacacia*), the honey locust or thorn tree (*Gleditsia triacanthos*) and the Kentucky coffee tree (*Gymnocladus canadensis*); and many weeds.

FIG. 198.—Alfalfa and clover.

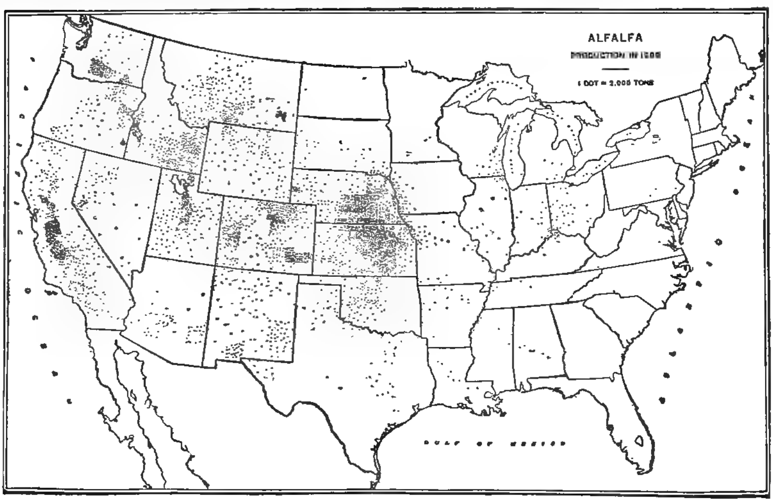


FIG. 199.—Distribution of alfalfa in United States. (From U. S. Census, 1910.)

LINACEÆ (Flax Family).—Herbs, occasionally shrubs; leaves alternate, simple; flowers in racemes or corymbs, symmetrical; sepals five (sometimes four or six); petals same in

FIG. 200.—Peanut plant with the elongated stems sending seeds into the soil shown at right and left.

number as sepals; stamens equal to petals and alternate with them, united at the base; carpels three to five, united at base to form a compound, dry, capsular fruit. The most important member of the family is the flax plant.

The common flax (*Linum usitatissimum*) and the narrow-headed flax (*L. angustifolium*) are important commercially. They probably originated in the sub-tropical regions of Hindustan and the Mediterranean, but are now grown in temperate regions. The early history of flax is unknown, but it was used extensively by the ancients. The fiber is used for the manufac-

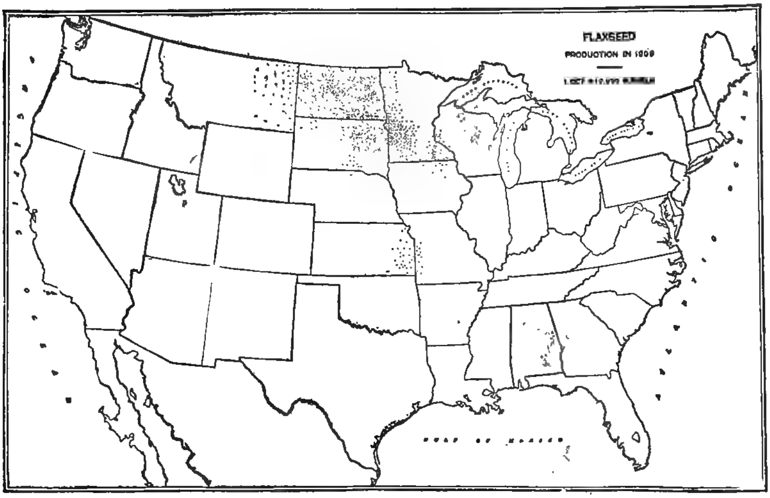


FIG. 201.—Distribution of flax production (seed) in United States. (From U. S. Census Report, 1910.)

ture of laces, linen, coarse cloth and cordage; the seeds are harvested for the manufacture of linseed oil, which is used in mixing paints and for many other purposes (Fig. 201).

GERANIACEÆ (Geranium Family).—Mostly herbs; perfect, usually symmetrical, five-merous flowers; leaves simple. This family includes the well-known geraniums which are cultivated so extensively as ornamentals, many wild geraniums, the wood sorrels (Oxalis), the touch-me-nots and jewel weeds.

RUTACEÆ (Orange or Citrus Family).—Shrubs and trees; leaves alternate; flowers perfect, sepals four or five, imbricated;

petals four or five, imbricated; stamens the same number or twice the number of petals (sometimes numerous); pistil compound;

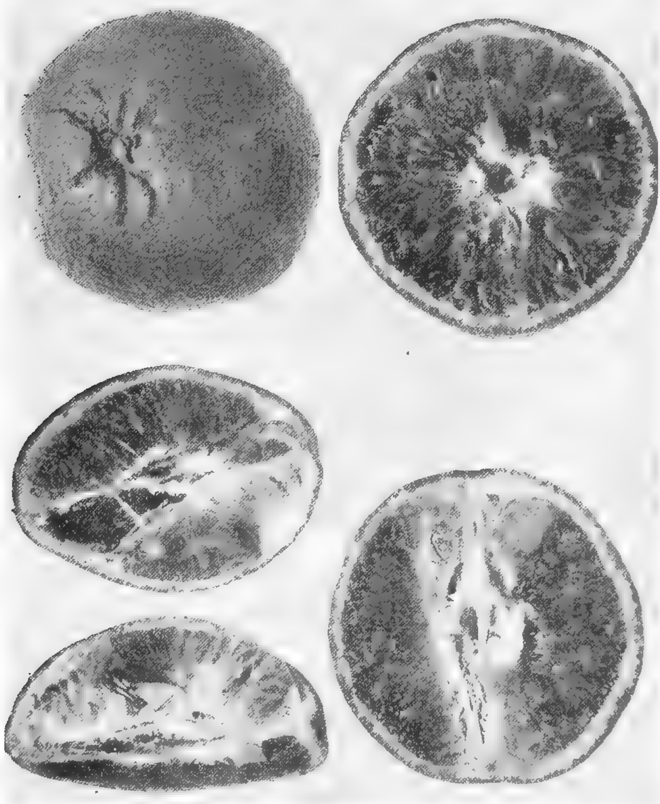


Fig. 202.—The sweet orange, often nearly seedless.

fruit a large berry. This family contains several valuable tropical fruits.

Among the most important are the many varieties of the orange (*Citrus aurantium* Linn.) (Figs. 202, 203), which is so well known on our markets. It is of Asiatic origin and was carried by the Crusaders to the Mediterranean regions of Europe and thence to America. It was brought to America by the Spaniards at a very early date and was later found growing wild.

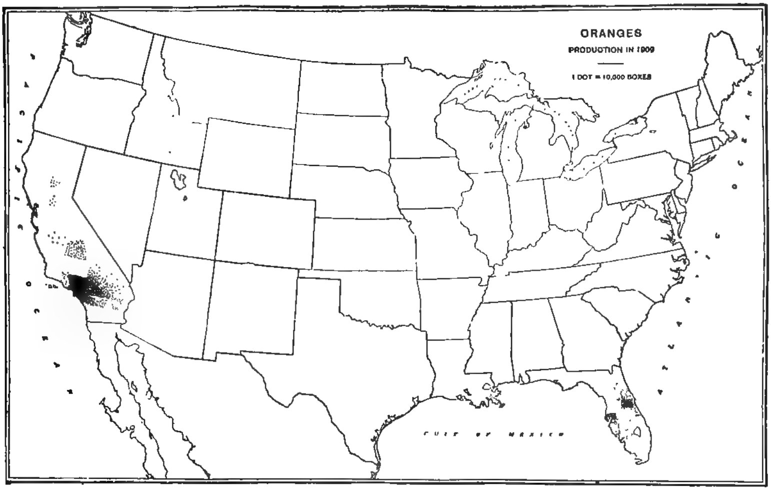


Fig. 203.—Orange production.

This misled the early explorers, who were for a time inclined to believe it indigenous to America.

Other important species are the shaddock (*C. decumana* Willd.), the lemon (*C. medica* Linn.), and many others.

ANACARDIACEÆ (Poison Ivy Family).—Shrubs or trees, some of them climbing; leaves alternate; flowers small, regular, perfect, diœcious or monœcious; sepals five to seven, united at the base; petals five, or absent; stamens five and alternate with the petals; pistil with three styles, fruit a one-chambered, one-seeded berry or drupe. Contains many plants which are poisonous.

The genus *Rhus* contains the common poison ivy or poison oak (*R. toxicodendron*), the poison sumach (*R. venenata*), the common sumach (*R. glabra*), and several other species.

Products from some of the species of this genus are used for the manufacture of high-grade tannins, in the making of dyes, varnishes and inks, and in medicine.

SAPINDACEÆ (Horse-chestnut and Maple Family).—Trees

FIG. 204.—Maple.

or shrubs; leaves simple or compound and opposite flowers mostly asymmetrical, often irregular, usually polygamous or diœcious; sepals four or five; petals four or five, and sometimes wanting; stamens five to ten, inserted on a fleshy disc; ovary two- or three-chambered, but only one ovule in each chamber maturing. A large and diversified family containing many important trees (Fig. 204).

The genus *Acer* includes the maples (Fig. 205); the genus *Æsculus*, the horse-chestnut and buckeye; and the genus *Staphylea*, the bladder nut.

The maples will be recognized as the most important members of this family. They are among the most prominent of our forest and shade trees and the wood is used for many purposes. The sap of the sugar maple (*A. saccharum*) is used extensively in the manufacture of sugar.

VITACEÆ (Grape Family).—Shrubs, usually climbing by tendrils; leaves alternate, palmately veined or compound; flower clusters and tendrils opposite the leaves; flower regular; sepals

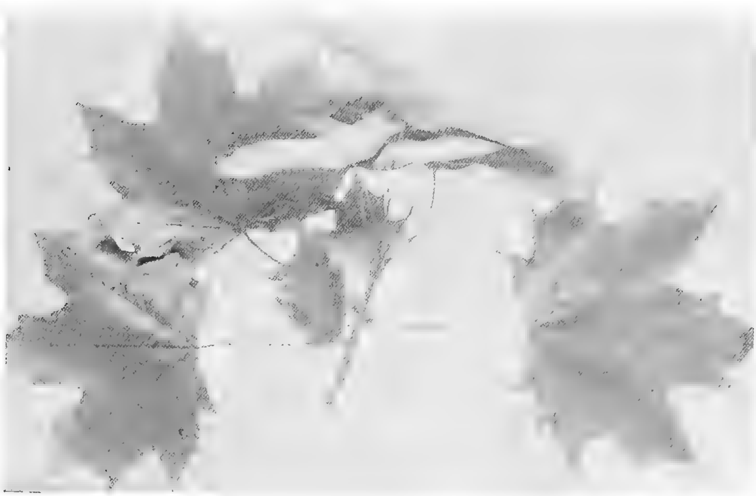


FIG. 205.—Maple.

very small; petals four or five; stamens five and opposite the petals; pistil short; fruit a pulpy berry.

The grape was cultivated in very ancient time, 4000 years or more B.C. It is indigenous to both the old and new worlds, but the two types are somewhat different; the old-world grapes, which have probably been derived from *Vitis vinifera,* include the wine- and raisin-producing varieties, while the American grapes, which have been derived from *V. rotundifolia* or the southern fox grape and *V. labrusca* or northern fox grape, are most valuable as table grapes. The history of the grape industry in America is very interesting and well worth reading (Figs. 206, 207).

This family also includes our native Virginia creeper (*Ampelopsis quinquefolia*), the Boston or Japanese ivy and several other ornamental plants.

Tiliaceæ (Linden Family).—Trees; flowers perfect in small cymes, hanging on an axillary peduncle which is attached to a ligulate, membranous bract; ovary five-chambered and de-

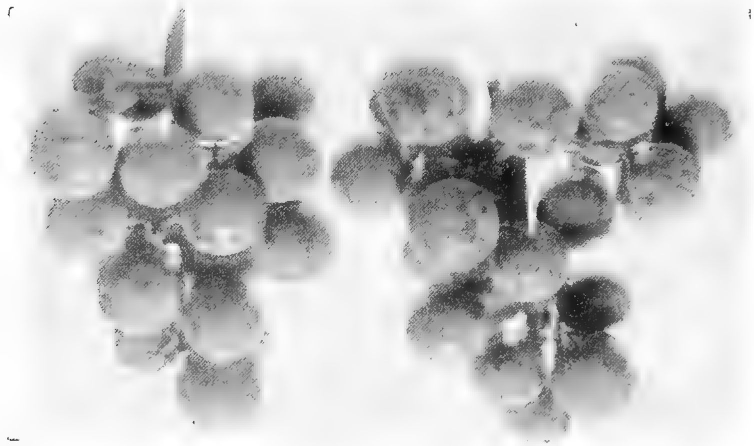


Fig. 206.—Modern improved grape.

veloping into a dry, woody, globular, indehiscent one-chambered, one- to two-seeded fruit; leaves simple, alternate, more or less heart-shaped and serrate. This family is represented by the genus *Tilia*, which includes several species of valuable trees known as basswoods or lindens.

Malvaceæ (Mallow Family).—Herbs or shrubs; leaves alternate, stipulate and palmately veined; flowers regular; sepals five, united at the base and valvate; petals five, convolute in the bud; stamens numerous, monadelphous in a column and united with the petals; anthers reniform; carpels several; ovaries several, united to form a several-chambered pod. This family includes a number of important plants.

Among the most important of these plants is the cotton (*Gossypium*), of which there are several species and many varieties. Among the most important are the herbaceous cotton (*G. herbaceum*), the sea-island (*G. barbadense*) and the tree

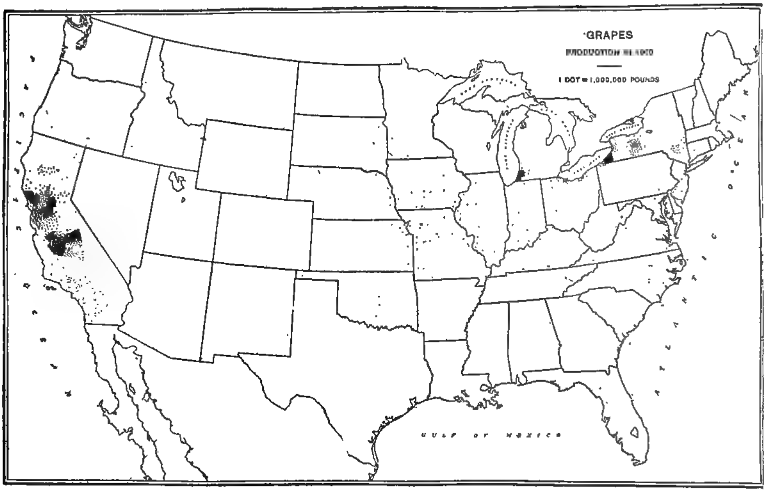


FIG. 207.—Grape production.

cotton (*G. arboreum*). It is a tropical and semi-tropical plant, but its exact origin is not known. It was used to some extent by the ancients, but was not used extensively for the manufacture of cloth until during the seventeenth century. It is claimed that the Spanish explorers found cotton growing wild in Mexico and that the fiber was used by the natives, but there is some doubt as to whether the plants in question were true cotton.

Cotton is used not only for the manufacture of cloth but also for the manufacture of gun-cotton, collodion and other products.

A very valuable oil is extracted from the seeds and the remaining solid parts are used for stock feed and for fertilizers (Fig. 208).

The okra or gumbo (*Hibiscus esculentus* Linn.) (Fig. 209) is of African origin, but its early history is unknown. It is grown in various parts of the United States and used in soups.

This family also includes many ornamentals, such as hollyhocks (Fig. 120) and the Athæas, as well as many weeds.

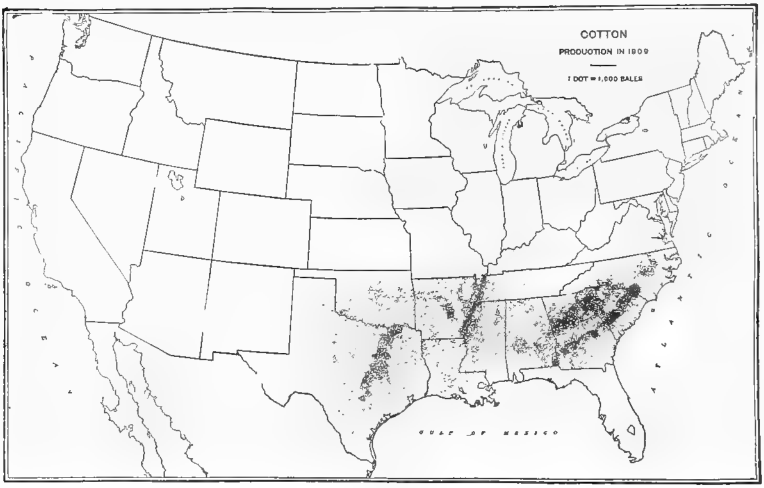


FIG. 208.—Cotton production.

VIOLACEÆ (Violet Family).—Herbs; roots fibrous; leaves alternate with stipules; inflorescence axillary and usually solitary; flowers perfect and irregular; sepals five; petals five and alternate with the sepals; stamens five; pistil one-chambered but with three carpels with parietal placenta; fruit a dry capsule (Fig. 211).

This family includes many species of violets and pansies. Many varieties are grown extensively for ornamental purposes.

FIG. 209.—Pods of okra or gumbo in green and ripe stages.

Fig. 210.—Hollyhock, representing the flower type of the mallow family.

UMBELLIFERÆ (Parsley Family).—Herbs; leaves alternate, usually compound, the petioles expanded or sheathing at the base; inflorescence simple or compound umbels; flowers small,

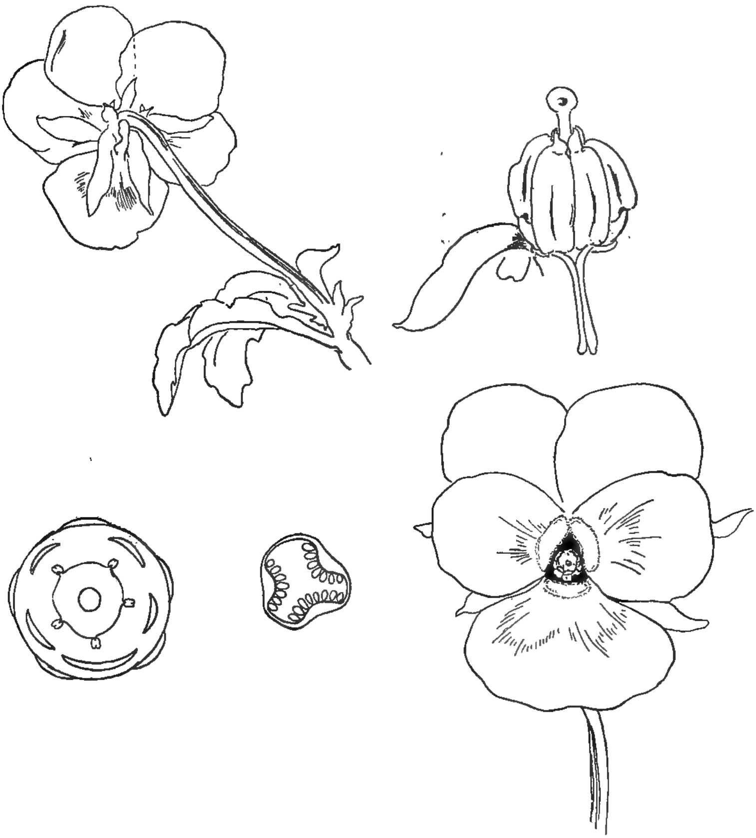


FIG. 211.—Pansy, showing arrangement of parts of flower.

sepals five; stamens five, epigynous on the inferior ovary; ovary two-chambered; fruit composed of two dry indehiscent achenes. Some of the species are poisonous, while others are used for food. This family also contains many weeds.

The celery (*Apium graveolens*) was known and used by the ancients; the anise (*Pimpinella anisum*) was known by the ancients and is grown for the oil which is extracted from the seeds and used in medicine; the parsnip (*Peucedanum pastinaca* or *Pastinaca sativa*) is a well-known food plant which originated in Europe; the carrot (*Daucus carota* var. *sativa*) (Figs. 212, 213), is another well-known food plant that was cultivated by the ancients; and the parsley (*Carum petroselium*) is another well-known food plant which has been used in Europe and Asia.

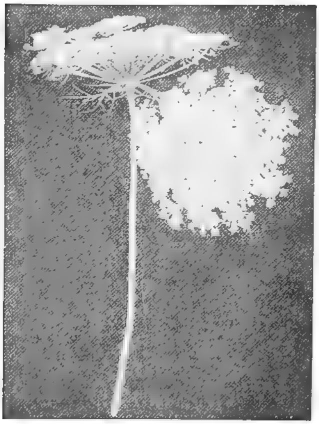


Fig. 212.—Wild carrot blossoms. The umbel type of inflorescence.

Cornaceæ (Dogwood Family).—Shrubs or trees (rarely herbs); flowers clustered (rarely solitary), perfect or imperfect; fruit a two-seeded drupe. This family is represented by several species of dogwood (*Cornus*) which are prized as ornamentals and two species of sour gum trees (*Nyssa*).

Caprifoliaceæ (Honeysuckle Family).—Shrubs (rarely herbs); gamopetalous, perfect flowers; fruit a berry, drupe or pod; leaves opposite. This family includes many very common and well-known plants, such as the elder (*Sambucus*), snowball (*Viburnum*) and honeysuckles (*Lonicera*).

Ericaceæ (Heath Family).—Herbs or shrubs; flowers perfect, regular or nearly so; calyx four- or five-lobed and adnate to the ovary; corolla four- or five-lobed and free; stamens eight or ten; ovary many-chambered; fruit a capsule, more rarely a berry. A very large and much diversified family. It includes the huckleberry (*Gaylussacia*), the blueberries and cranberries

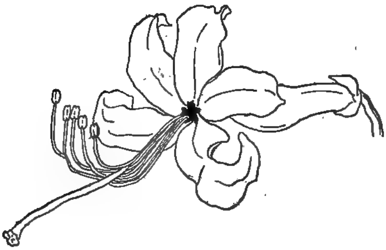
(*Vaccinium*); the trailing arbutus (*Epigea repens*), the American laurel (*Kalmia*), the azalea, rhododendron, the Indian pipe (*Monotropa*) and many other plants (Figs. 214, 215, 216).

FIG. 213.—The long form of carrot.

OLEACEÆ (Olive Family).—Shrubs and trees; leaves opposite, simple or pinnate; calyx gamosepalous and four-lobed or wanting; corolla gamopetalous, four-lobed and short; stamens two (rarely three or four); ovary two-chambered, with two (rarely more) ovules to each chamber; fruit a capsule, berry, drupe or a samara.

This family includes our well-known ash trees (*Fraxinus americana* and other species), the fringe tree (*Chionanthus vir-*

FIG. 214.



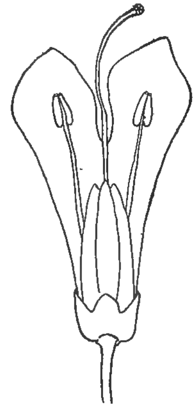
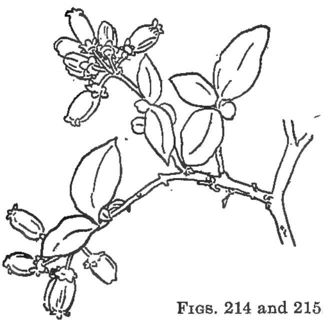
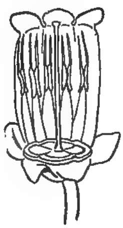
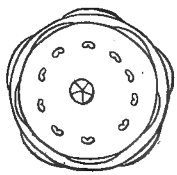


FIG. 215.







FIGS. 214 and 215.—Types of flowers of Ericaceæ.

ginica), the privet (*Ligustrum vulgare*) which is used so extensively for hedges, and the olive (*Olea europæa*), which is a native of Syria but is now widely distributed. The fruit is eaten raw or dried, is made into pickles, or used for oil, which is used in salad dressings. The wood is fine-grained, takes an excellent polish and is used to manufacture many small articles.

ASCLEPIADACEÆ (Milkweed Family).— Herbs, with milky juices; flowers perfect; pollen in waxy or granular masses; fruit a large, follicular pod containing seeds frequently with feathery development for scattering. This family is represented by the common milkweeds (*Asclepias*).

CONVOLVULACEÆ (Morning-glory Family).—Herbs, usually

FIG. 216.—Cranberries.

climbing or trailing; leaves alternate; inflorescence solitary or in one-sided scorpioid cymes, axillary or terminal; flowers perfect, usually regular; sepals five; corolla gamopetalous and five-lobed; stamens five, on the petals; ovary two- or three-chambered; fruit a dry capsule. This is the family of the morning-glory but includes many other plants.

The sweet potato (*Ipomœa batatas*) is a tropical and semitropical plant, which is grown and used extensively for food. Its origin is not definitely known; some authorities claiming that it is Asiatic while others claim that it is indigenous to both Asia and America.

The dodder or love vine (*Cuscuta*) also belongs to this family. There are many species, all of which are parasitic on other plants. The seeds germinate in the soil, the stem twines about other plants, the lower part dies, thus leaving it attached to its host. Some species are destructive to agricultural plants, especially the clovers.

LABIATÆ (Mint Family).—Mostly herbs with square stems; flowers axillary, in cymose clusters or spikes or racemes; perfect, irregular; fruit developed into four achene-like lobes or nutlets; leaves simple, opposite or whorled and aromatic. This family contains a great many interesting plants. A few will be mentioned.

Mentha piperita is the well-known peppermint and *Mentha viridis* the spearmint. One or both of these plants were cultivated in Europe as early as the ninth century. They are used for flavoring and to some extent in medicines. *M. puegium* is the pennyroyal which has been introduced from the old world. It also possesses some medicinal properties.

This family also contains sweet thyme (*Thymus vulgaris* and *T. serpyllum*), which is used for seasoning and in medicines; the well-known garden sage (*Salvia officinalis*), which was introduced from the old world and is used for flavoring in foods; catnip or catmint (*Nepeta cataria*) and hoarhound (*Marrubium vulgare*), which have certain medicinal properties.

SOLANACEÆ (Nightshade Family).—Herbs, rarely shrubs; leaves alternate; inflorescence solitary, fascicled or corymbose, axillary or terminal; flowers perfect, usually regular; sepals five (four or six), united at the base; petals five (four or six), united at the base or to form a campanulate tube; stamens attached to the corolla and alternate with its lobes; ovary two or more chambered; fruit a many-seeded dry capsule or pulpy berry. A large family containing many economic plants.

The potato (*Solanum tuberosum*) is a very familiar plant which was given to the world by America. The Spanish ex-

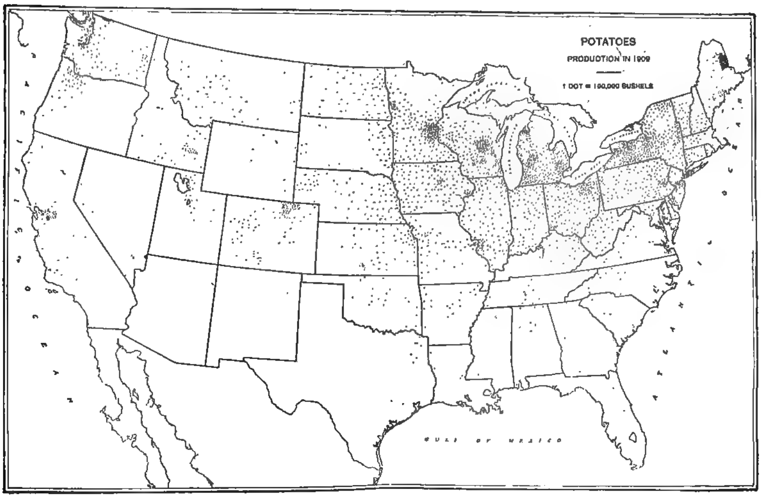


FIG. 217.—Potato production.

plorers found it cultivated by the natives of the cooler Andean regions. The method of its introduction into Europe is somewhat uncertain. Some believe that it was carried to Spain by the Spaniards and also to Florida and from there to Virginia and from thence to England. Others believe that potatoes were found on a Spanish ship which was captured by the English and then introduced into the British Isles. The Europeans were very slow to learn its food values, and it is said to have been first used in Ireland, which probably accounts for the common name of "Irish potato." The name "white potato" is much more appropriate.

There are a great many varieties of potatoes and they are

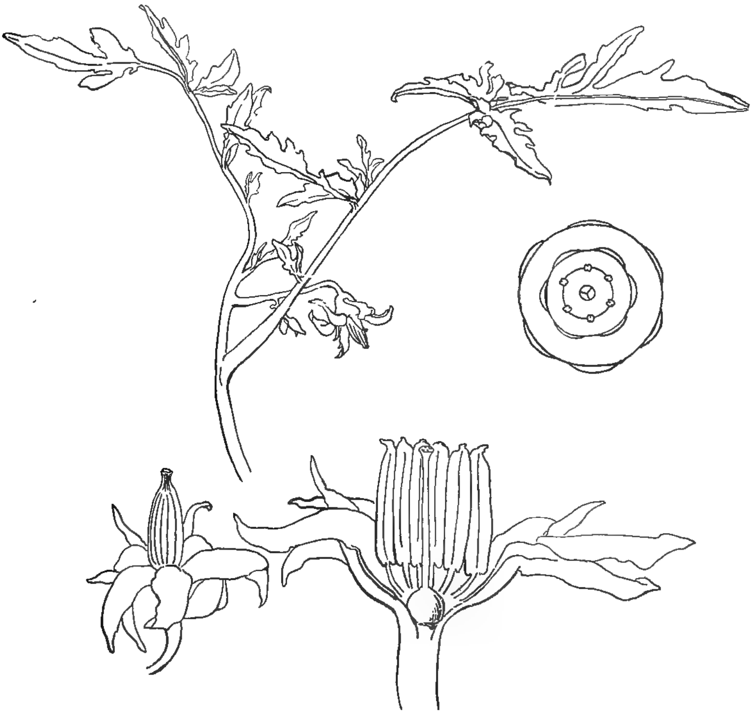


FIG. 218.—Tomato blossoms.

extensively cultivated and used throughout the greater part of the civilized world.

Short, cool seasons are especially satisfactory for the growing of the potato. The extreme northern states and Canada are noted for their production of potatoes and furnish most of the seed for the growing of this crop in other states. Although this crop is grown throughout the greater part of the United States and large crops are produced in some localities, the best seed tubers come from the cool regions (Fig. 217).

The tomato (*Lycopersicum esculentum*) is another contribution of the New World. The plants and flowers are very similar to those of the potato, but in this case we use the fruits instead of the tubers. It is a native of Central and South America and was introduced into Europe by the Spaniards. It

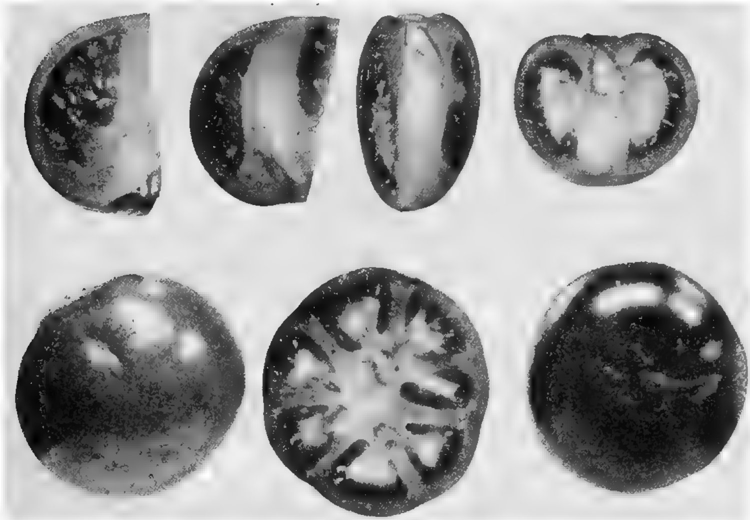


FIG. 219.—Tomatoes.

came into prominence as a food plant about 1840 and there are now great numbers of varieties (Figs. 218, 219).

The red pepper (*Capsicum annuum*) (Fig. 220), Cayenne pepper (*C. fastigiatum* and *C. frutescens*) and other species are also American products which were introduced into Europe by the Spaniards. Both the plant as a whole and the flower are somewhat different from the potato and tomato, but the relationship is very evident.

(These plants must not be confused with the black pepper, *Piper nigrum,* of the family *Piperaceæ,* which is an Asiatic plant).

The tobacco (*Nicotiana tabacum* and other species) is another American plant which is not so useful as the preceding plants of this family. It was introduced into Portugal in 1558, into Spain in 1559, and into England in 1586. It is extensively

FIG. 220.—The sweet pepper.

grown and used throughout a large part of the world. The active principle is the alkaloid nicotine, which is a deadly poison. The plant is quite different in appearance from the preceding. It is erect and the leaves are prominent; the flowers are long, tubular or funnel-shaped; the fruit is a dry capsule containing great numbers of seeds.

This family also contains many other species, such as the deadly nightshade (*Atropa belladonna*), the bitter-sweet (*Solanum dulcamara*), the Jamestown or jimson weed (*Datura stramonium*) and many species of ground cherries (*Physalis*).

BIGNONIACEÆ (Bignonia Family).—Woody plants (trees or climbers); flowers large, showy and perfect; fruit a dry capsule containing many large, flat, winged seeds; leaves simple or com-

FIG. 221.—Cucurbit blossom.

pounds, usually opposite. Mostly tropical but represented in the north temperate zone by the well-known trumpet flower (*Tecoma radicans*) and the catalpa (*Catalpa speciosa* and *C. bignonioides*).

CUCURBITACEÆ (Gourd Family).—Herbs, mostly trailing or climbing; leaves alternate, palmately veined or lobed; inflorescence solitary, sometimes fascicled or racemed; flowers mostly imperfect, monœcious or diœcious; five-parted gamosepalous, bell-shaped calyx; five-parted gamopetalous wheel or bell-shaped corolla; stamens five (or by union apparently three); ovary inferior, one- to many-chambered; fruit a many-seeded berry. Mostly tropical and sub-tropical and containing many economic plants (Fig. 221).

The common cucumber (*Cucumis sativus*) is widely distributed throughout the world and is considered one of our most

FIG. 222.—Ribbed type of cantaloupe.

important garden crops. The many varieties of muskmelon and cantaloupe (*C. melo*) are Asiatic plants which were grown by the ancients and are now widely distributed throughout a considerable part of the world (Fig. 222).

The common watermelon (*Citrullus vulgaris*) is an African plant which was cultivated by the ancient Egyptians. Although it originated in the tropics, its cultivation is practiced far into the temperate zones.

The squashes (*Cucurbita melopepo, C. verucosa, C. maxima,* etc.), pumpkins (*C. pepo*) and gourds are well-known plants. The pumpkin is said to be an American plant.

This family also contains a great many wild plants.

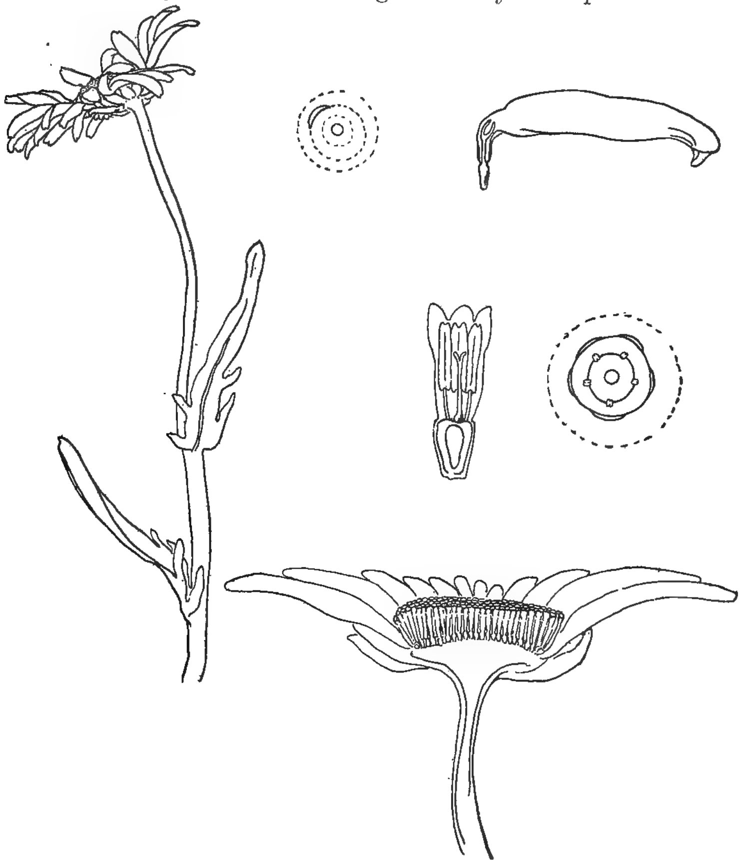


FIG. 223.—Composite flower.

COMPOSITÆ (Composite Family).—Mostly herbs; leaves alternate or opposite, frequently cleft, without stipules; inflorescence a close flat head surrounded by involucral leaves; flowers small, perfect, polygamous, monœcious or diœcious; the marginal flowers when present are known as the ray flowers and have strap-shaped corollas, the central or disc flowers may be of this same type or may be tubular; the calyx is rudimentary (sunflower) or hairy (dandelion) and adheres to the ovary; the

FIG. 224.—Sunflower head. Composite type of inflorescence.

corolla is five-parted and gamopetalous; stamens five, attached to the corolla, anthers united into a tube around the style; style two-cleft; fruit a one-seeded achene (Figs. 223, 224).

This family includes many ornamental plants, such as chrysanthemums, asters, daisies, sunflowers (Fig. 136), etc., and many weeds, such as ironweed, goldenrods, fleabane, rosinweeds, ragweeds, burdock, thistle, dandelion, etc.

The Jerusalem artichoke (*Helianthus tuberosus* Linn.) was first mentioned as a food plant in 1616. Its early history is not well known, but it probably came from the northern part of the United States or Canada.

Lettuce (*Lactuca scariola*, var. *sativa*) is a well-known salad plant which was cultivated by the ancient Greeks and Romans,

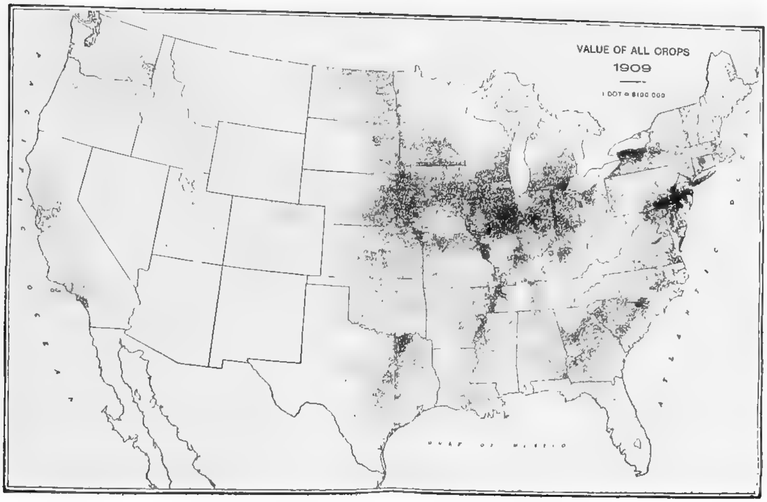


Fig. 225.—Distribution of crop production in U. S.

but its early history is not known. It probably originated in southeastern Asia.

The chicory (*Cichorium intybus* Linn.) is cultivated for salad, as a vegetable, and for the roots, which are mixed with coffee. Its early history is obscure, but it probably originated in eastern Europe and western Asia.

The endive (*C. endivia* Linn.), which is also grown for salad, probably originated in the same part of the world.

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